Calibrating Value Estimates of Requirements

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ABSTRACT
Selecting requirements for implementation of software applications depends on the subjective judgements of the stakeholders who participate in the task. We claim that portfolio analysis provides a market driven, systematic, and more objective approach to supplement the selection of requirements, and also accounts for uncertainty and incomplete knowledge in the real world. We illustrate through two examples, how portfolio-based reasoning facilitates calibrating – that is, aligning – our value estimates of requirements with capital market valuations.

Keywords
Requirements prioritisation, portfolio-based reasoning, CAPM

1 INTRODUCTION

It is generally accepted that the choice of requirements selected for implementation significantly determines customer satisfaction [10; 12; 16; 19]. The need to select requirements stems from the obvious necessity to fit within an allocated project resource pool and to resolve conflicts in stated functional and non-functional requirements. Moisiadis [11] highlights the strengths and weaknesses of the two approaches most commonly cited to prioritise requirements in practice, namely, Quality Function Deployment (QFD) [18] and the Analytical Hierarchy Process (AHP) [7; 9; 15]. Except for the Distributed Collaboration and Prioritisation Tool (DCPT) [13], these and other prioritisation approaches (e.g., [6]) fail to explicitly account for uncertainty and incomplete knowledge in the real world.

However rigorous prioritisation approaches may be, they nonetheless depend on the subjective judgements of the stakeholders who participate in the task. Given the diversity of their backgrounds, skills, and personal agendas, it is unrealistic to expect that the various rankings and cost-value estimates that they produce is consistent and objective over time. Therefore, there is a critical need to calibrate (adjust) the inputs to all the prioritisation approaches. This will then ensure a more accurate assessment of customer satisfaction that results from the implementation of the selected requirements. Indeed, Zave [19] affirms this need by identifying "understanding priorities and ranges of satisfaction" as a distinct area that could benefit from discovery and articulation of new principles.

In this paper we propose a market driven, systematic, and more objective approach to supplement the selection of requirements, which also accounts for uncertainty and incomplete knowledge in the real world. We show that portfolio-based reasoning is well suited to drive software engineering decisions because it makes the connection to market value explicit [1].

The remainder of the paper is organised as follows: Section 2 introduces the core logic of portfolio theory from finance in order to clarify its applicability to the resource allocation problems for software systems. Section 3 illustrates, through quantitative analysis of two examples, the link between requirements and their market adjusted value. Finally, section 4 concludes the paper by discussing the necessity of considering the economic dimension as an important factor of software engineering decision-making.

2 PORTFOLIO-BASED REASONING

This section is a brief introduction to the core logic of the Mean-Variance Portfolio Theory adapted from [3; 14]. Portfolio analysis quantifies how to optimally make the trade-off between risk and expected return.

We interpret asset prices as proxy for *value*. We define a *portfolio* as a combined holding of more than one asset by an investor; *uncertainty* as an event that can happen, but the probability of its occurrence is unknown; *risk* as an event with potentially undesirable outcome whose occurrence has some known probability distribution.

We restrict our world to one in which investors can choose a set of risky assets (e.g., securities or stocks) and a safe asset that has a risk free rate of return 'r' over the holding

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period (e.g., fixed term bank deposit). We denote the return on an individual asset by R_i and the expected return of an individual asset by ER_i (= μ_i). We assume that the risk on an individual asset 'i' can be measured by the variance, σ^2_i (= $var(R_i)$) or standard deviation σ_i of its return. All individuals have homogeneous expectations about expected returns, variances, and covariances (= $\sigma_{ij} = cov(R_i,R_j)$, i.e. correlations between the various returns). Transaction costs and taxes are assumed to be zero.

The CAPM provides a model of the determinants of the equilibrium expected return ER_i on any *individual* risky asset in the market. It predicts that the expected excess return on an individual risky asset (ER_i – r) is directly related to the expected excess return on the market portfolio (ER_m – r) with constant of proportionality given by the beta (β) of the risky asset: $(ER_i - r) = \beta_i (ER_m - r)$ where $\beta_i = cov(R_i , R_m) / var(R_m)$. ER_m is the expected return on the market portfolio, that is, the average expected return from holding *all assets* in the optimal proportions w^*_i. $Cov(R_i , R_m)$ is the covariance between the return of the security i and the return on the market portfolio, and $var(R_m)$ is the variance of the market.

The basic intuition of beta (β) is that it measures the *sensitivity of change* in the return of an individual security to the change in return of the market portfolio. That is, the beta is a measure of the *contribution* of a security to the risk of the portfolio. A useful property is that the average beta across all securities, when weighted by the proportion of each security's market value to that of the market portfolio, is 1. That is, $\Sigma^N_{i=1} w_i\beta_i = 1$.

The expected return on the market is the sum of the risk-free rate plus some compensation for the risk in the market: ER_m = r + Risk premium. Historically, the average risk-free rate in the U.S. capital markets for over seventy years was 3.7%, and the average expected return on individual securities was 12.2% [5]. Thus, the average risk premium was 8.5%.

Under plausible conditions, the relationship between expected return and beta can be represented by the following equation:

$$ER_i = r + \beta_i \times (ER_m - r) \quad (1)$$

This is referred to as the Capital-Asset-Pricing Model (CAPM), and implies that the expected return on a security is linearly related to its beta. Historically, (ER_m - r) has been positive. Equation (1) implies that the expected return on a security is *positively* related to its beta, as illustrated in Figures 1,2. This relationship corresponds to a straight line called the Security Market Line (SML). It is upward sloping as long as the expected return on the market is greater than the risk-free rate. Because the market portfolio is a risky asset, theory suggests that its expected return is above the risk-free rate. Empirical evidence (the 8.5% mentioned above) supports this.

The shape of the line implies that *the expected returns on securities that lie above or below the SML will be adjusted until they lie on the line*. If the SML itself were curved, many securities would be wrongly valued. In equilibrium, all securities would be funded only when valuations changed so that the SML became straight – linearity would be restored.

3 LINKING REQUIREMENTS TO MARKET VALUE

In this section we illustrate the correspondence of the portfolio selection problem to the software decision problem – allocating limited resources (budget, skills etc.) among the candidate requirements (source of benefits). We revisit a frequently cited work on prioritising requirements using AHP [8; 9] and demonstrate how to make the link to market value explicit. AHP compares alternative requirements in a stepwise fashion and measures their contribution to a given goal [15]. In the fist example from the RAN project [9], 14 high-level requirements (R1 . . . R14) that cover the main system functionality are identified. Representatives of the stakeholders are then asked to perform 91 (=14*(14-1)/2) pair wise comparisons, using a predefined scale, first according to value and then according to implementation cost. In the second example from the PMR project [9], there are 11 high-level requirements (R'1 . . . R'11) resulting in 55 (=11*(11-1)/2) pair wise comparisons. Each requirement's determined value and cost estimates are relative and based on a ratio scale. A cost-value plot divided into three distinct areas (high, medium, low) clearly shows the requirements' importance (estimated values) in relation to their corresponding development effort (estimated costs). It is worth noting that although the inputs to AHP are estimates – predictions with inherent uncertainty – they are not treated as such.

We now recast the problem by treating each requirement as a risky asset (security) and assume that the estimate for a requirement's value represents the expected return ER_i (or ER'_i) on asset-i. Strictly speaking, we could redefine value by subtracting costs and accounting for options[1] which we choose to ignore here. We also assume that the relationship between effort and expected return is linear (i.e. assets may be exchanged). Finally, we assume that the historic average risk-free rate (3.7%), and the average expected return on an individual security (12.2%) apply to these project contexts as well. This is a reasonable assumption since it is generally argued by financial economists that the best estimate of the risk premium (the difference 8.5%) in the future is the average risk premium in the past [5].

[1] Options capture the notion that there is value in having flexibility to wait for better information before irreversibly committing valuable resources to develop or acquire assets [17].

Under these assumptions and using equation (1), we can calculate the betas shown in the appendix (Tables 1, 2). The rows labelled ER_i and ER'_i are borrowed from [9]. By plotting the expected returns of the requirements against their corresponding betas we can check the accuracy of the estimates relative to the real world (represented by the SML) as shown in Figures 1, 2. The expected returns on the requirements that lie above the SML are undervalued, while the ones that lie below the SML are overvalued. In efficient markets, all values should lie on the SML. The three values on the top right of Figure 1 represent R1, R6, and R13 respectively. Between them they account for 49% of value and 35% of cost of the requirements of the RAN project under the original AHP analysis. Similarly, the three values on the top right of Figure 2 represent R'4, R'6, and R'5 respectively. Between them they account for 63% of value and 51% of cost of the requirements of the PMR project under the original AHP analysis. Under portfolio analysis, and subject to the assumptions given above, they are undervalued. Therefore, according to CAPM, the selections resulting from the AHP prioritisation in Karlsson and Ryan's case studies should not attract funding as stipulated.

Due to insufficient relevant data in the referenced paper, we have not calculated the betas according to the following definition: $\beta_i = cov(R_i , R_m) / var(R_m)$. Nonetheless, as crude as the assumptions are, the numbers are sufficiently persuasive that the economic dimension is an important factor in software decision-making.

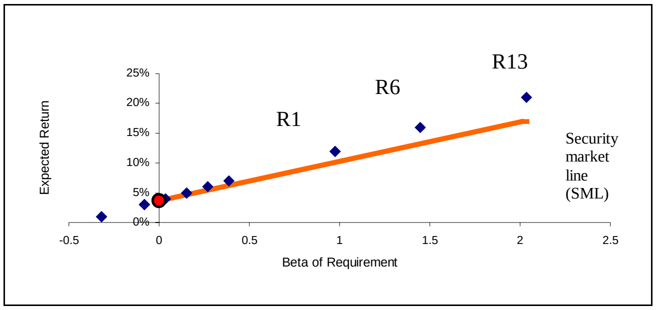

FIGURE 1 RELATIONSHIP BETWEEN EXPECTED RETURN ON AN INDIVIDUAL REQUIREMENT AND ITS BETA FOR THE RAN PROJECT

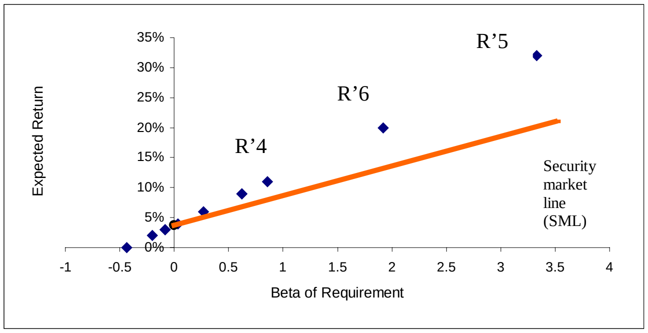

FIGURE 2 RELATIONSHIP BETWEEN EXPECTED RETURN ON AN INDIVIDUAL REQUIREMENT AND ITS BETA FOR THE PMR PROJECT

4 DISCUSSION AND CONCLUSIONS

Portfolio-based analysis has previously been explored in comparing alternative combinations of validation techniques for deadlock detection, and choosing among competing security technologies for a given a set of threats [2]. The approach rests on a number of assumptions similar to the ones made above. Key among them is the assumption that the relationship between effort (cost of various resources) and benefit (expected return) is linear – that assets can be exchanged freely. This is clearly not the case in software decision-making and the problem is under investigation by a number of researches.

However, by submitting to CAPM, we have in effect sidestepped the trap (of comparing alternative combinations of software resources) and yet calibrated the value estimates relative to the market – that is, made them consistent with capital market valuations – using publicly available data. We achieved this by highlighting discrepancies between market pricing and subjective estimates. For example, the prioritisation that would result from AHP in [9] will certainly differ from the original ranking if the value estimates are revised as suggested above. Consequently, our confidence in achieving customer satisfaction will increase and with it the probability of attaining our business goals as determined by the market.

In our introduction, we proposed that portfolio analysis is a market driven, systematic, and a more objective approach to select requirements, which also accounts for uncertainty in the real world. We can now justify this claim by arguing that the notion of value in a software application is ultimately determined by how well its functionality matches the expectation and meets the satisfaction of its stakeholders. Every commercial company's capital budgeting decisions, including investments in software, are in the long run subject to market valuation. Markets assign value to publicly held companies not only according to their present worth, but also by incorporating an assessment of present value of uncertain future gains. The valuations are objective and systematic across all companies and markets for, if it were not so, arbitrage[2] would ensue to restore equilibrium. Finally, the fact that the beta is a measure of risk relative to the market underscores the remaining portion of the claim viz. that the approach is market driven and accounts for uncertainty in the real world.

We use the term value to denote a quantification of the concept of importance, worth, or desirability. However, value under uncertainty is best determined with options thinking that gives a principled way to reason about how to balance countervailing incentives to time investment

[2] Buying an asset in one market at a lower price and simultaneously selling an identical asset in another market at a higher price [14].

decisions [4], such as the selection of requirements for the next release of a COTS software product, the selection of COTS components, or the development of program families. With a real options perspective, we can view requirements selection as the creation of a portfolio of options. A good selection decision allows the product to evolve successfully (even profitably) by creating valuable options.

Valuation of requirements based on potential competitive impact is fundamentally different from valuation based on cost. The success or otherwise of software systems in fast changing commercial settings can be better ascertained on an ongoing basis by making the connection to value explicit i.e. by being aligned with the market. We aimed to capture the irreducible core logic of portfolio analysis, to demonstrate that it provides systematic guidance and feedback towards achieving that connection.

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APPENDIX

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14
ER_i	12%	6%	5%	7%	12%	16%	3%	3%	4%	5%	1%	1%	21%	3%
β_i	0.98	0.27	0.15	0.39	0.98	1.44	-0.08	-0.08	0.04	0.15	-0.31	-0.31	2.04	-0.08

TABLE 1 THE ESTIMATED VALUES AND THEIR CORRESPONDING BETAS FOR THE RAN PROJECT

	R'1	R'2	R'3	R'4	R'5	R'6	R'7	R'8	R'9	R'10	R'11
ER'_i	0%	6%	3%	11%	32%	20%	9%	4%	2%	9%	3%
β_i	-0.44	0.27	-0.08	0.86	3.33	1.92	0.62	0.04	-0.2	0.62	-0.08

TABLE 2 THE ESTIMATED VALUES AND THEIR CORRESPONDING BETAS FOR THE PMR PROJECT