Expert Judgments in the Cost-Efficiency Analysis of Technology Portfolios

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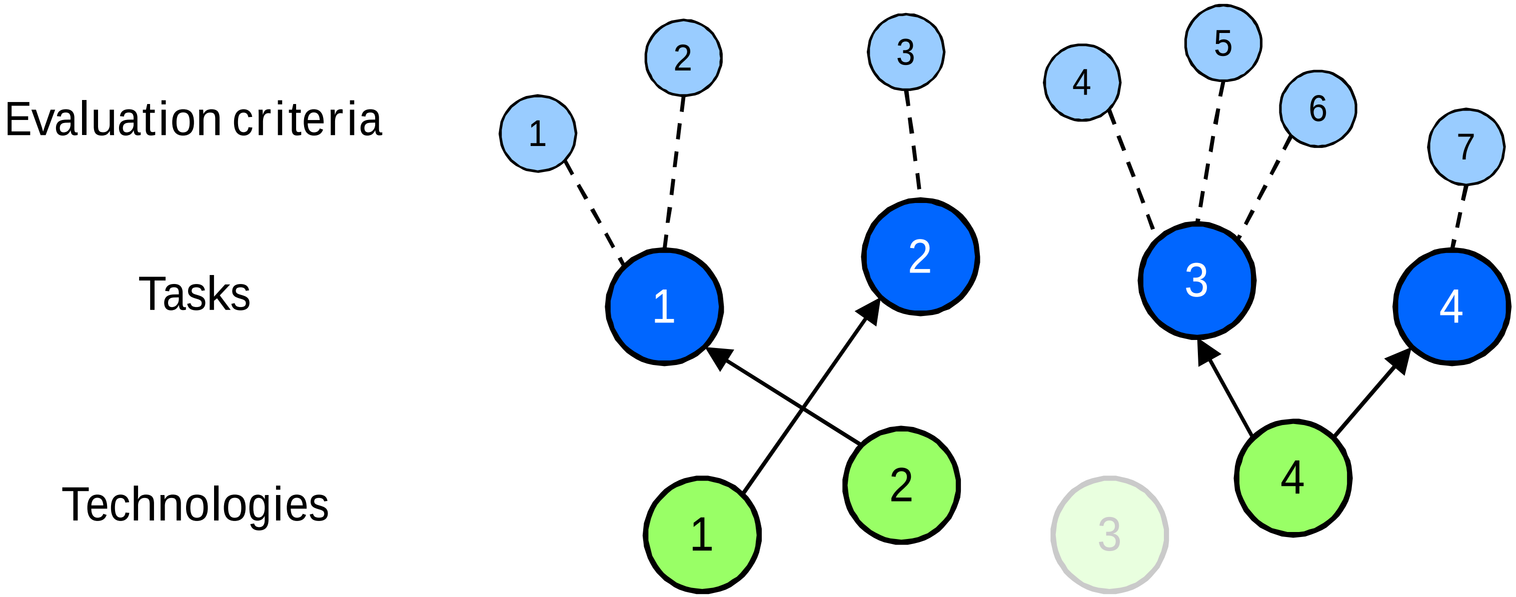
Technology Assignment Problem

- Technology portfolios consist of technologies and their assignments to complete different prespecified tasks

- The objective is to identify cost-efficient portfolios
  - Minimize total cost and maximize overall value of completed tasks



Challenges in the Evaluation of Technologies

- Uncertainties about the performances of technologies to complete different tasks
  - Completion levels are measured with regard to multiple criteria

- Incomplete information about the importance of criteria
  - Relative importance of criteria may depend on the context

- Interactions and incompatibilities between technologies
  - Possible synergy advantages in performances and costs

- Utilizing multiple sources of information
  - Judgments from multiple experts and/or simulators

Modeling Technology Portfolios

- Technology portfolio is denoted by a matrix $\mathbf{p} \in \{0,1\}^{m \times n}$
  - *m* technologies and *n* criteria

$$p_{ij} = \begin{cases} 1, \text{if technology } i \text{ is assigned to impact on criterion } j \\ 0, \text{otherwise} \end{cases}$$

$$c_{ij} = \text{cost of assigning technology i to impact on criterion j}$$

$$v_{ij} = \text{performance of technology i on criterion j}$$

- Feasible portfolios P_F satisfy all relevant constraints
  - Budget constraints, incompatibility constraints etc.
  - Multiple technologies assigned to perform one task is modeled using dummy technologies

Overall Value and Multiple Information Sets

- Overall value is approximated by an additive value function

$$V(\mathbf{p},\mathbf{v},w)=\sum_{j=1}^{n} w_j \sum_{i=1}^{m} p_{ij} v_{ij}, \quad \mathbf{v}\in[0,1]^{m\times n}, w\in S_w=\left\{w\in R_+^n \middle| \sum w_j=1\right\}$$

- Total cost of portfolio $C(\mathbf{p})=\sum_{j=1}^{n}\sum_{i=1}^{m} p_{ij} c_{ij}$

- Evaluation information about the performances (v) and weights (S_w) are obtained from multiple experts

$$\begin{matrix} (\mathbf{v}^1, S_w^1) & \cdots & (\mathbf{v}^1, S_w^M) \\ \vdots & \ddots & \vdots \\ (\mathbf{v}^N, S_w^1) & \cdots & (\mathbf{v}^N, S_w^M) \end{matrix}$$

Incomplete Information and Cost-Efficiency

- Instead of point estimate weights, a set of feasible weights
  - For instance, rank-ordering statements are possible

$$S_w = \left\{ w_1 \geq w_2 \geq \cdots \geq w_n, w_j \geq 0 \,\forall j, \sum w_j = 1 \right\}$$

- Portfolio p^1 dominates portfolio p^2 if it has greater or equal overall value for all feasible weights according to (v, S_w)

$$\mathbf{p}^1 \succ \mathbf{p}^2 \Leftrightarrow \begin{cases} V(\mathbf{p}^1, \mathbf{v}, w) \geq V(\mathbf{p}^2, \mathbf{v}, w) \text{ for all } w \in S_w \\ V(\mathbf{p}^1, \mathbf{v}, w) > V(\mathbf{p}^2, \mathbf{v}, w) \text{ for some } w \in S_w \end{cases}$$

- Feasible portfolio that is not dominated by any less or equally expensive portfolio is cost-efficient $(P_{CE} \subseteq P_F)$
  - A set of cost-efficient portfolios for each information set (v, S_w)

Core Indices of Technology Portfolios

- The rationale is to identify portfolios that are cost-efficient (or inefficient) according to the statements of all experts

- Core index (CI) is the proportion of evaluations that supports a given portfolio is cost-efficient

$$CI(\mathbf{p}) = \frac{\left\|(\mathbf{v}, S_w) \text{ s.t. } \mathbf{p} \in P_{CE}(\mathbf{v}, S_w)\right\|}{\left\|(\mathbf{v}, S_w)\right\|} \times 100\%$$

- CI(p)=100% if and only if portfolio p is cost-efficient according to the statements of all experts

Core Index	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
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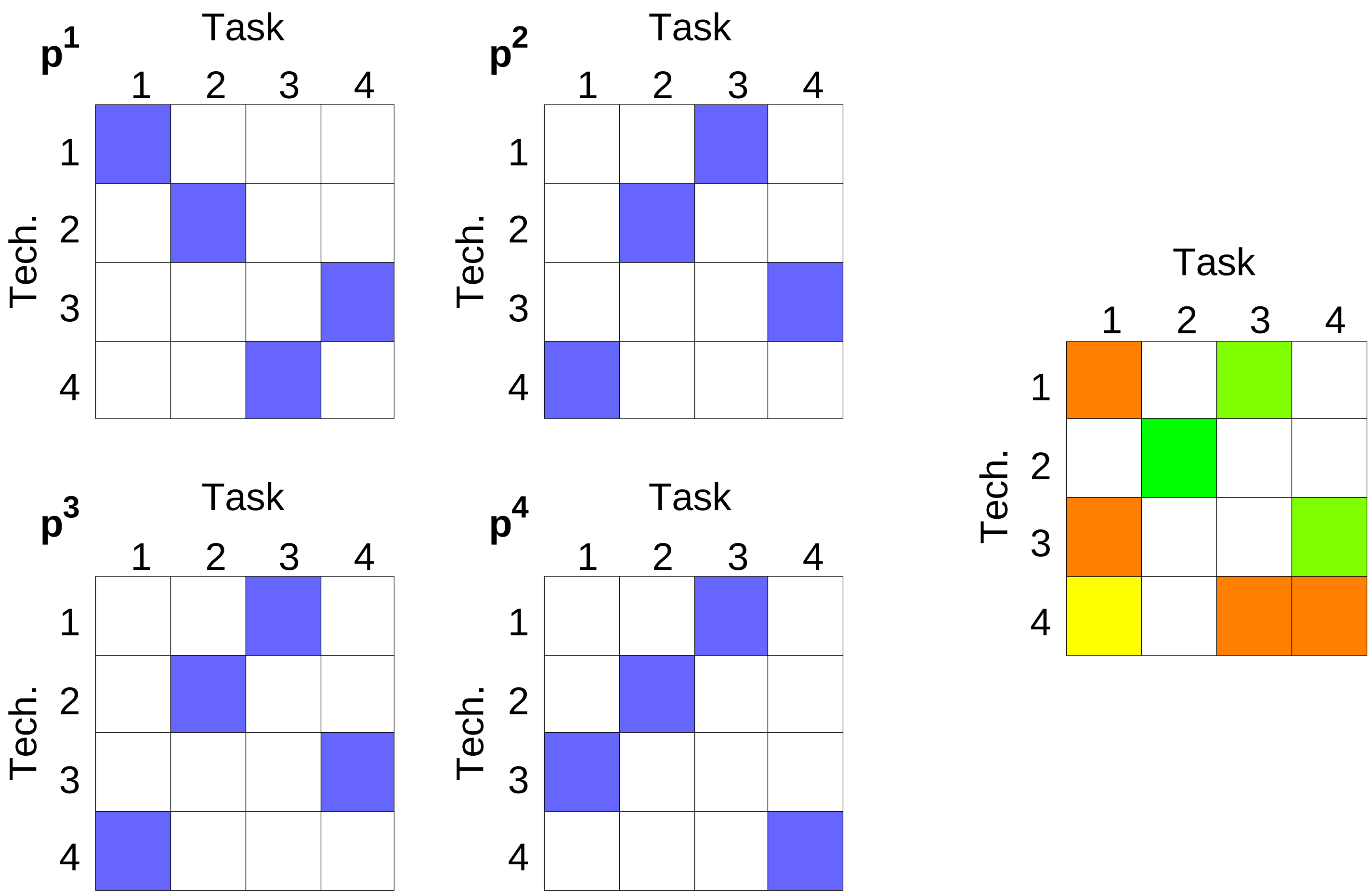
Core Indices of Technology Assignments

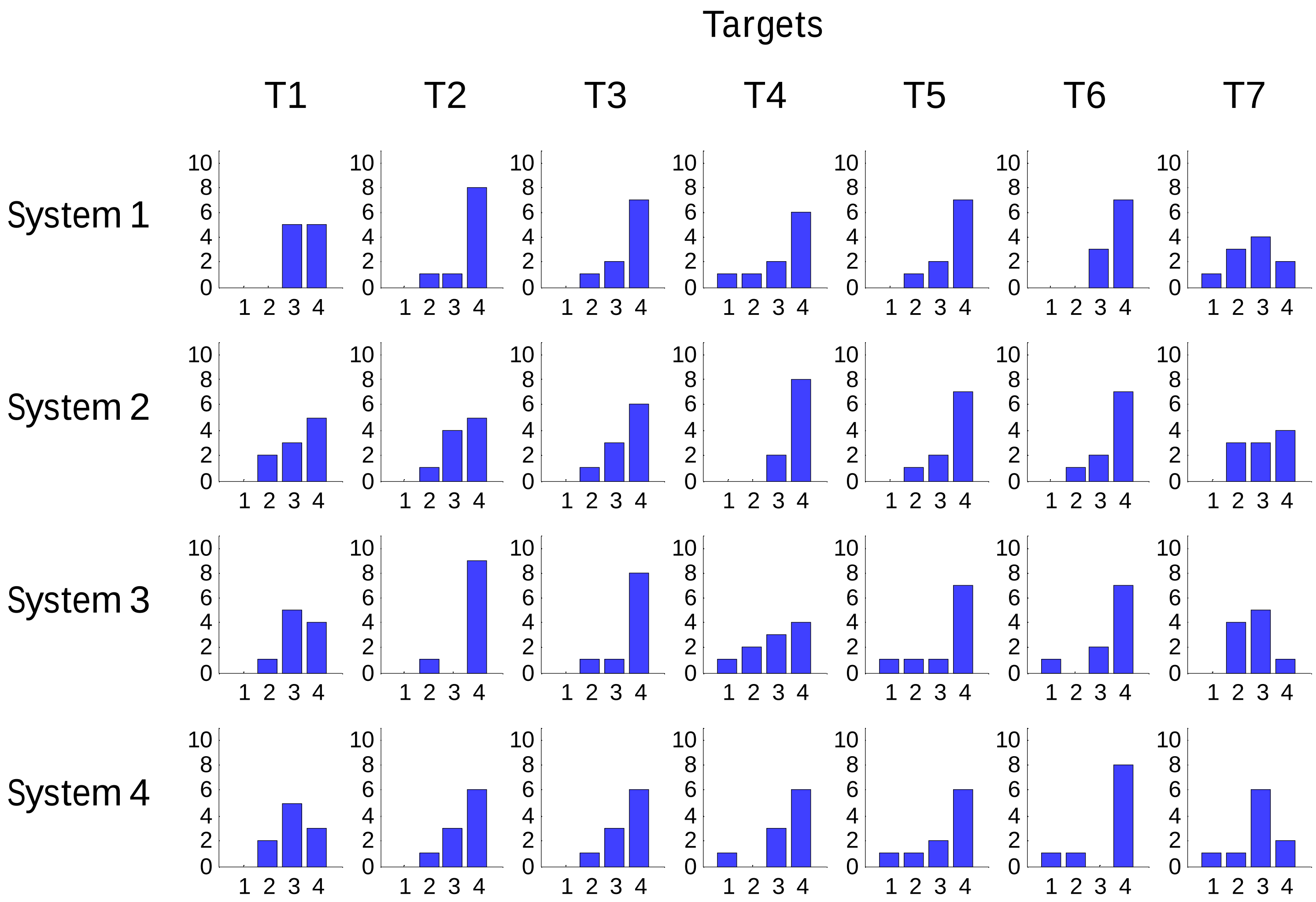


Numerical Example from Military Planning

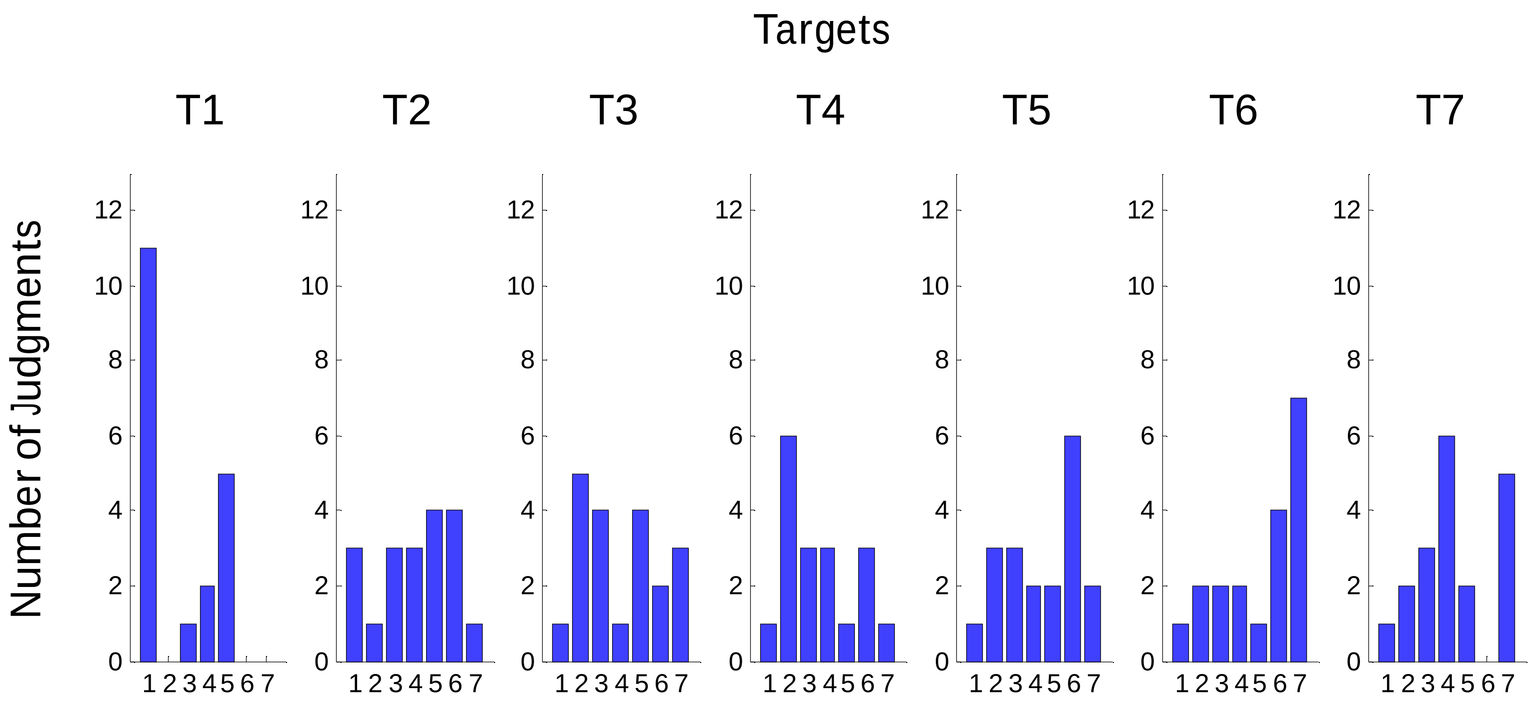
- Four different military tasks need to be completed using four alternative weapon systems
  - Only one type of weapon system used to complete one task
- The completion of tasks are evaluated with regard to seven enemy targets
  - The level of damage measured on a discrete scale 1-4
    "1 = Target is not damaged . . . 4 = Target is totally destroyed"
  - Judgments from 10 experts
- Incomplete information about the importance of targets
  - Priority rankings of targets from 19 experts
- Relative unit costs of weapon systems

  System 3 (1.00) < System 1 (1.09) < System 2 (1.14) < System 4 (1.20)

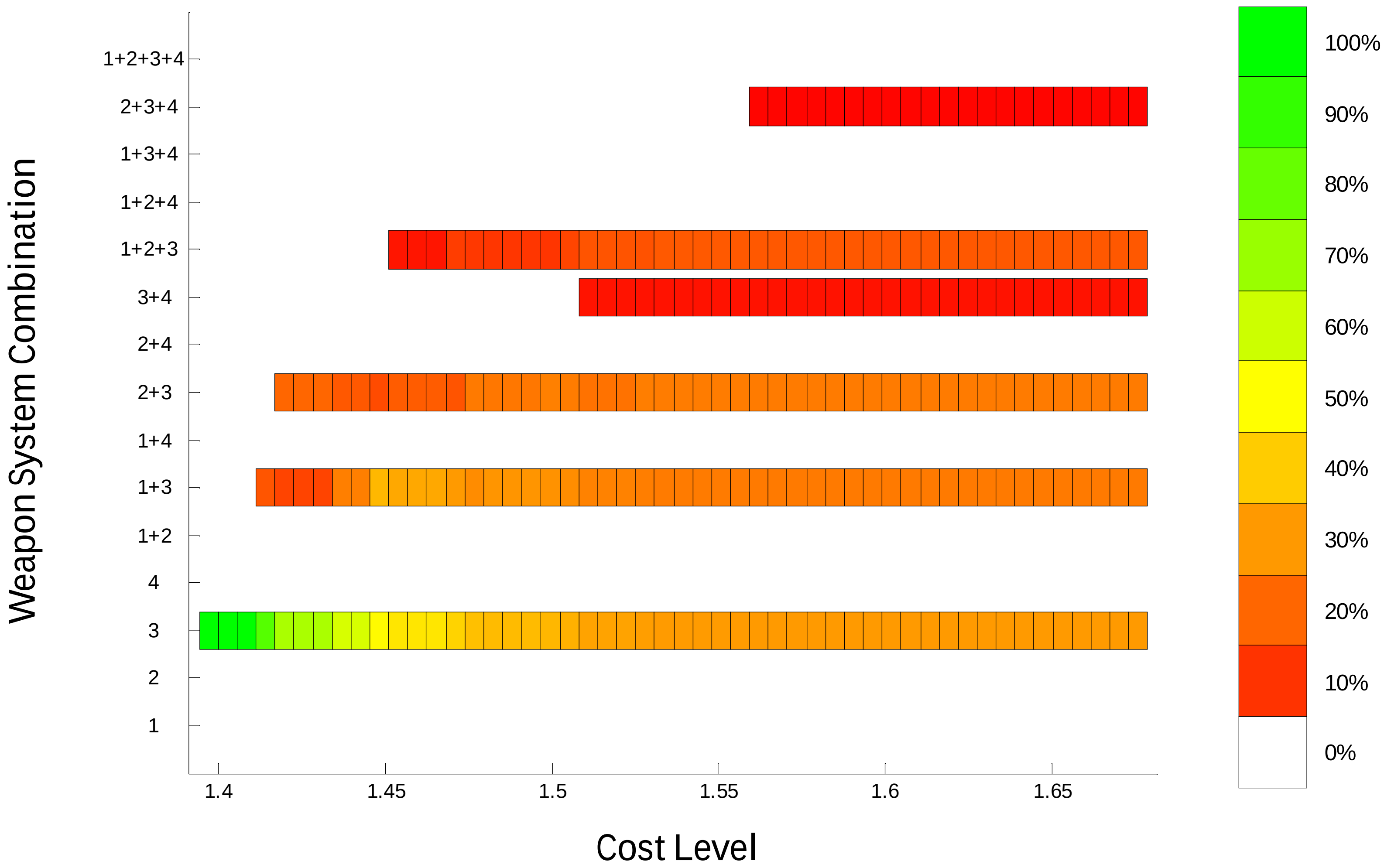
Distribution of Performance Judgments



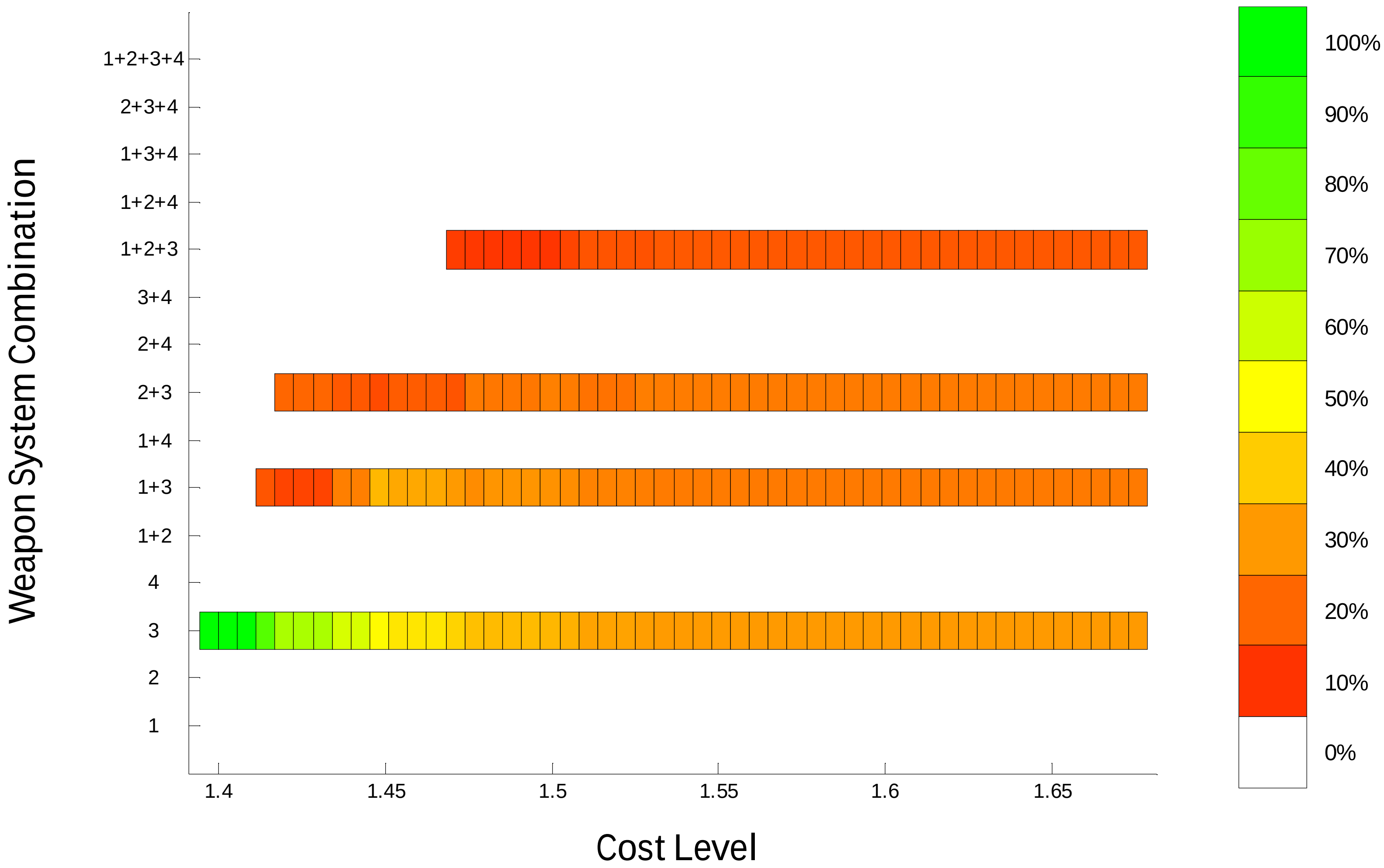
Distribution of Priority Rankings



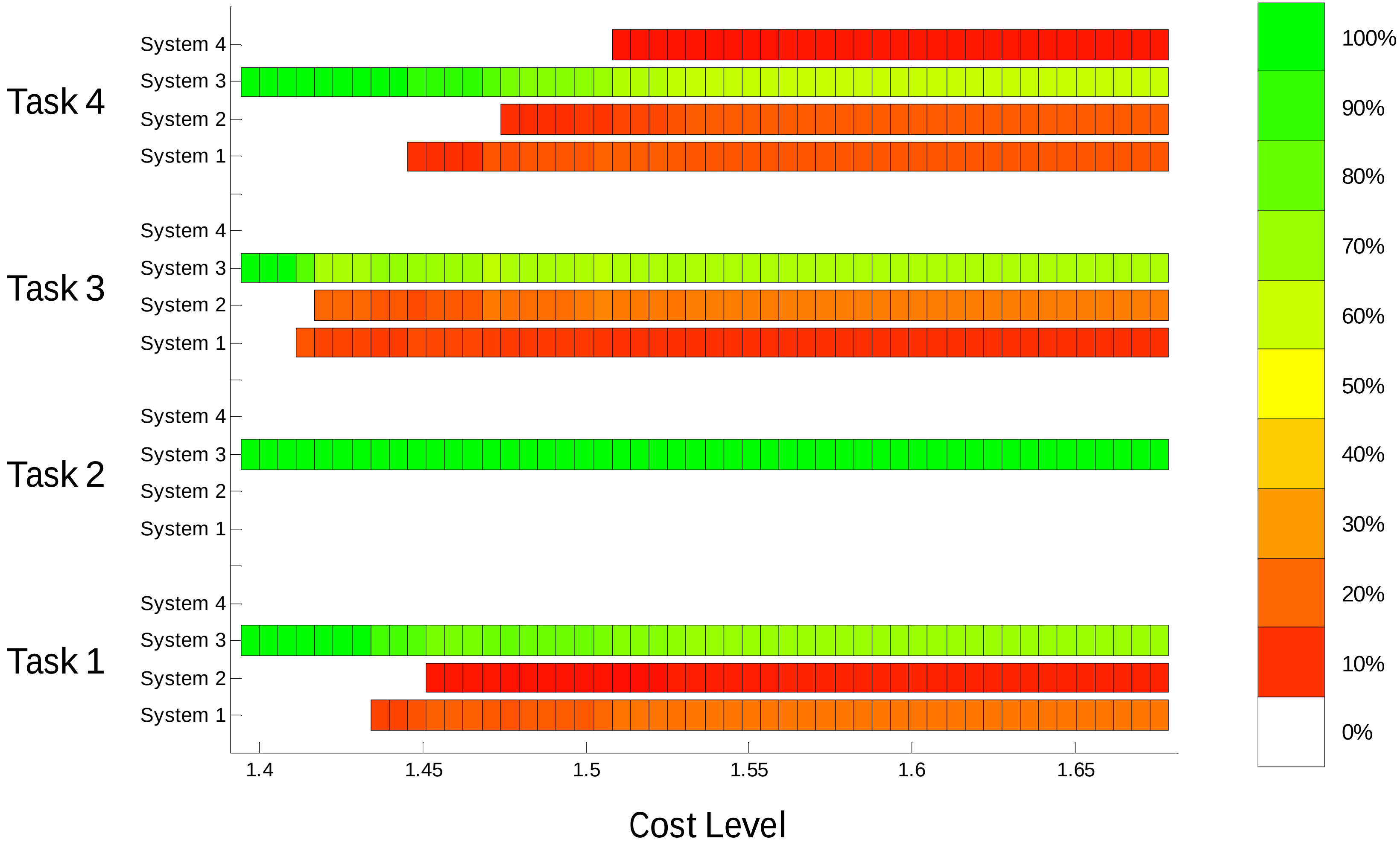
Cost-Efficient Combinations



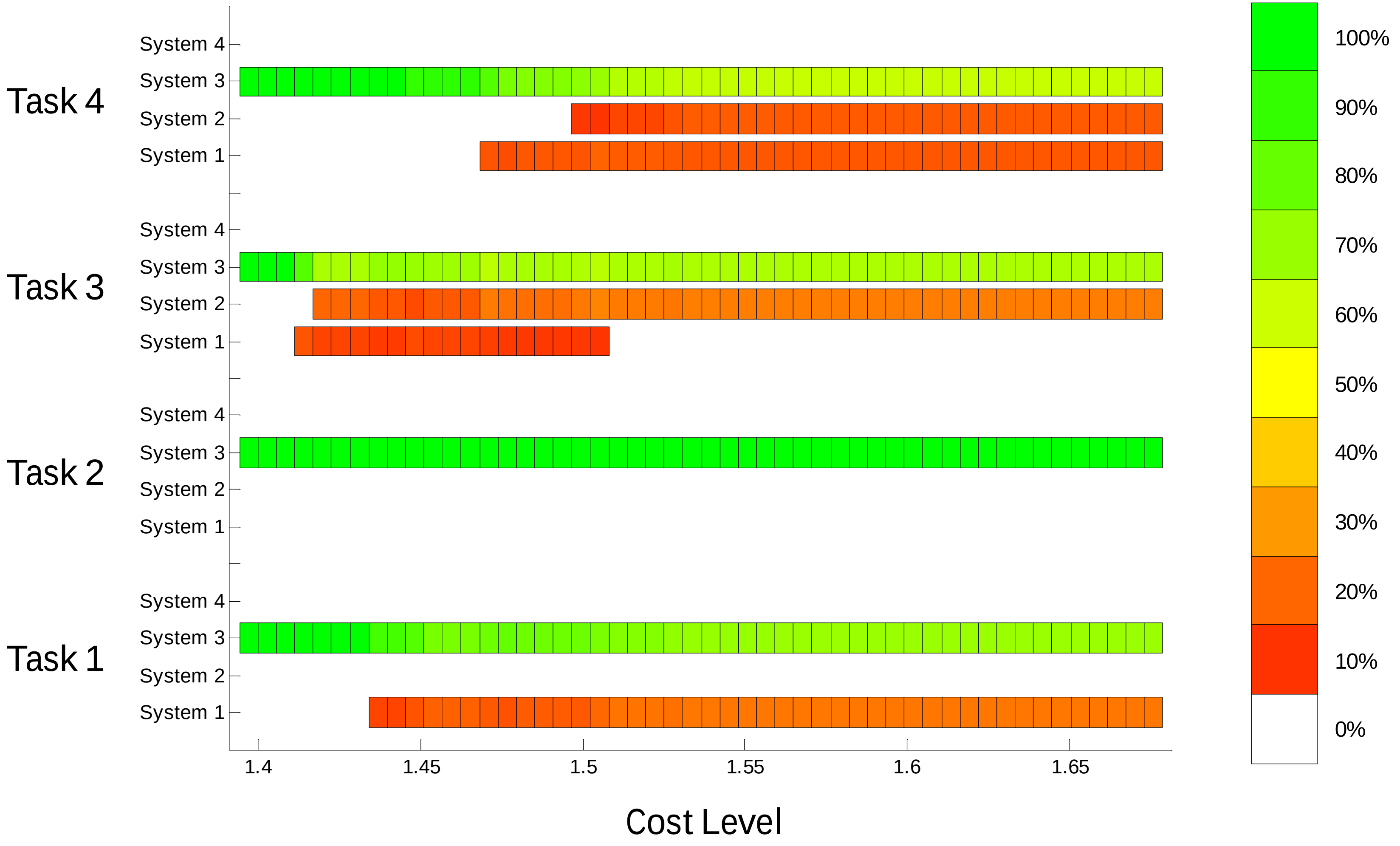
Cost-Efficient Combinations (CI>10%)



Cost-Efficient Assignments



Cost-Efficient Assignments (CI>10%)



Conclusions

- Portfolio approach captures possible interactions and synergies between technologies
- Evaluation information is estimated using judgments from multiple experts
- Cost-efficiency analyses according to the judgments of all experts at different cost levels
  - Analyses are not based on combined judgments (e.g. averages)
- Combining the judgments before analyses can lead to results that are not consistent with individual experts

References

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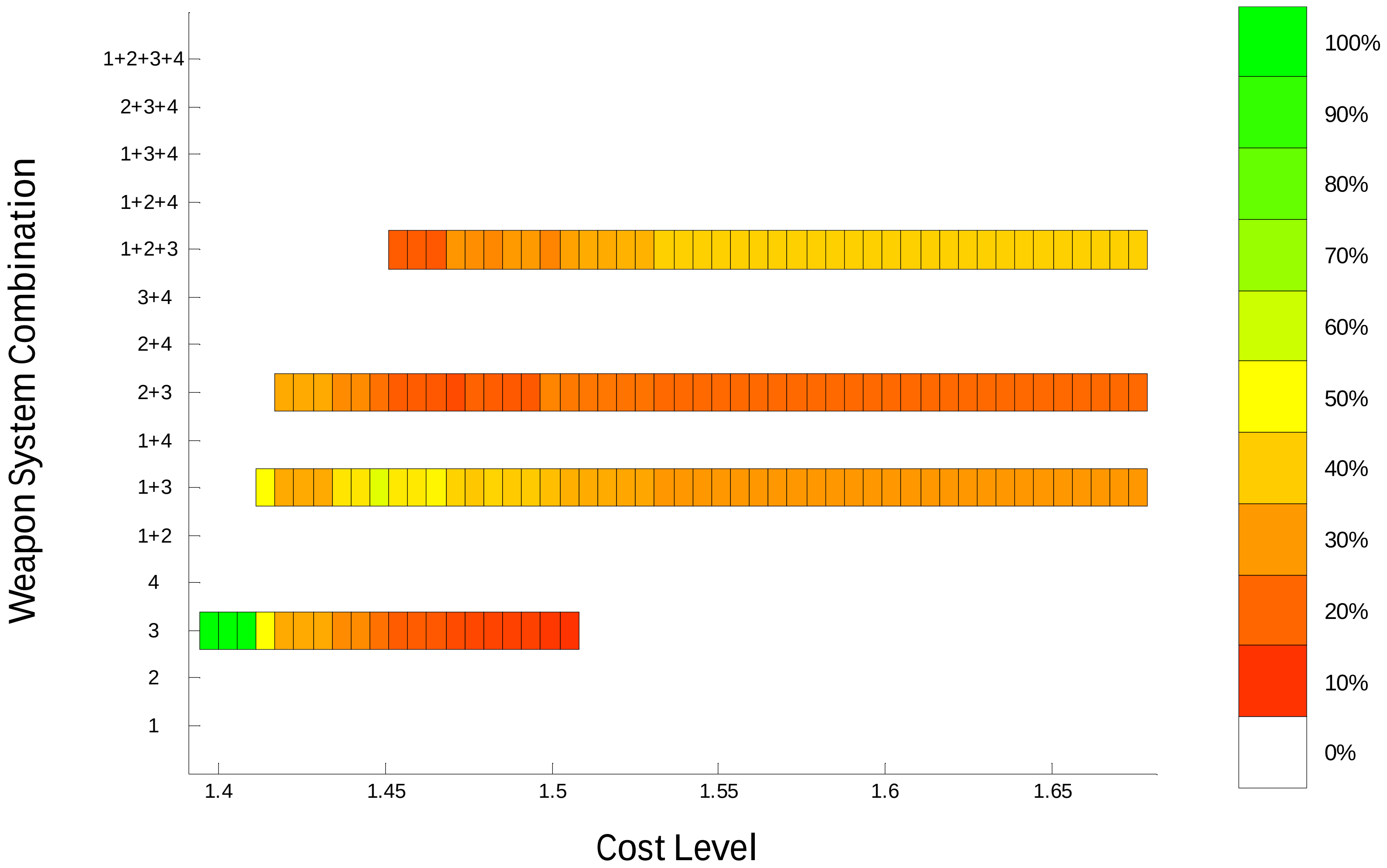
Extensions and Further Research

- Considering complementary tasks with different evaluation criteria
  - Can be integrated to model for instance using probabilities
  - Risk and robustness measures for portfolios can be formed
- Incomplete information about the costs
  - Can be modeled using multiple estimates or interval values
- Developing efficient algorithms for large problems
  - Approximative algorithms may be needed

Cost-Efficient Portfolios (averaged v)



Core Indices of Assignments (averaged v)