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Structured Decision-Making with DMRCS: Define-Measure-Reduce-Combine-Select

By Christine M. Anderson-Cook and Lu Lu

At the heart of Six Sigma is an approach to structured problem-solving. The DMAIC (Define-Measure-Analyze-Improve-Control) process guides users through a sequence of steps to determine the right scope for their problem, select the correct metrics to characterize the process to be improved, and understand its current performance. The final two steps use design of experiments to evaluate and select a best path forward, and formulate a plan for how to sustain the gains introduced into the process. One of the keys to the success of DMAIC is how it takes an often complex and unstructured problem-solving situation and translates the solution to a series of steps for which tools and approaches can readily be described.

Another scenario common in business and industry is decision-making when balancing multiple competing objectives. If a decision involves optimizing over just a single objective, then this is typically straightforward and can be done with little complication. Where things get difficult are situations where we have multiple facets to consider, and no clear way of ordering how to value the different aspects of the decision. Think about some of the most recent difficult decisions that you have wrestled with – weren't the hard parts all about how to measure and choose between trade-offs: For example, (1) spend more for better quality or save money at the expense of reduced quality; or (2) pay a little extra or sacrifice a bit of quality to save some time. The critical part of these decisions is coming to grips with how cost, quality and time are valued relative to each other. This can be greatly complicated by these dimensions being measured in different units and having different value to us in different situations. In today's world where expertise is distributed among many stakeholders, we are often making these challenging decisions as part of a team, where consensus is needed about how we balance these trade-offs between alternative potential solutions.

In this paper, we describe a 5-step process to evaluate and balance competing objectives in a structured and defensible way, while still allowing the flexibility to incorporate and evaluate different subjective weightings of the facets of the decision. Similar to DMAIC, we break this complex process into (hopefully) manageable steps, and describe the key aspects for each. The 5 steps are: Define-Measure-Reduce-Combine-Select (DMRCS, which we propose can be pronounced as "DeM-ReCS").

DEFINE – As with the DMAIC process, the first step is to clarify the scope of the exercise, which involves identifying the problem to be solved, the facets of the decision that are valued, and what potential solutions might exist. This step is critical for framing the key components of the decision to ensure that the correct problem is solved.

MEASURE – Second and also common to DMAIC, we need to be confident that we have high quality data on which to base our decision. The facets of the decision need to be translated into quantitative metrics with precise definitions to allow fair and consistent comparisons between potential solutions for a given facet. If high-quality quantitative measures of the characteristics of importance cannot be used, then the quality of the decision may be compromised.

REDUCE – Third, triage of the identified criteria may lead to some metrics being deemed secondary to the primary objectives of the decision. In addition, choices based on the primary criteria from a collection of potential solutions can be eliminated from further consideration based on their objective inferiority to other available options. A Pareto Front [1, 2] can be constructed, which includes only those options that represent rational good choices. These options are the only ones that we need to consider in subsequent stages. Trimming the number of solutions considered allows more meaningful exploration of the alternatives, but it is essential that no worthwhile solutions are spuriously eliminated.

COMBINE – Next, we consider ways of combining the different metrics, often measured on different scales, into comparable forms. This allows us to examine leading contenders while incorporating and evaluating our priorities for a good final solution. Finding ways of examining different metrics in comparable ways is the key to understanding the important trade-offs.

SELECT- Finally, we examine our prioritized solutions, compare them to close competitors and select a final choice which matches our priorities. Using graphical tools to help understand the relative merits and weaknesses of the alternatives can help build a team consensus as well as allow us to formulate a coherent justifiable explanation for our particular choice.

The remaining of the paper illustrates the DMRCs process using a job search example. Susan has unique skills that are highly sought after by a number of employers. After an extensive job-searching, Susan received 25 job offers that are very different in many important aspects. Knowing the importance of choosing the best job for her, she wants to make a comprehensive decision based on a quantitative evaluation of the options (job offers) and their relative trade-offs.

DEFINE

The goal is to select the best job offer for her from the 25 offers received. To use the 5-step process, Susan begins in the DEFINE step by identifying the facets of the decision that are valued, i.e. the criteria (valuable features) of interest. After evaluating which aspects felt most exciting about some jobs or least appealing about others, the following criteria were identified: (1) salary, (2) work environment, (3) location, (4) potential for promotion, (5) short or long term, (6) schedule, and (7) benefits. In considering which characteristics to focus on, it was essential to consider those for which data were available and which summarized the appeal of the job for her. It is also important to think broadly about diverse aspects of the decision, and not have multiple metrics for similar dimensions.

MEASURE

In the MEASURE step, appropriate metrics are chosen for the above listed criteria to quantify the performance of the candidate solutions (job offers) for all of the criteria under consideration. Salary is natural to measure as a numerical criterion, with values ranging between \$42K-\$90K per year for her available choices. By defining a scale between 0 (worst) and 10 (best), with particular characteristics associated with different scores [3], the desirability of characteristics (2), (3), (4), (6) and (7) can be quantified. Note that for some attributes (such as location), it is possible to finely distinguish between choices. For other characteristics (such as potential for promotion), the options have less distinctions with many choices sharing common scores. Short or long term is naturally categorical with only two values. The scoring process to assign values for all of the jobs is vitally important to making a good decision. All subsequent steps hinge on having the ordering of the alternatives within each of the criteria correct and representative of how valued a job is within that category. The criteria values for all the job offers are summarized in Table 1.

REDUCE

Next in the REDUCE step, Susan wants to reduce the possible options by eliminating obviously inferior offers. First, after careful consideration, Susan decides that salary and short/long term are “deal-breakers” for her. Given a rich set of alternatives, she decides that accepting a short term position would not feel satisfying. In addition, given the range of salaries being offered, she eliminates those jobs with a yearly salary lower than 65K dollars. Hence, 11 offers (shown in gray in Table 1) are excluded from further consideration.

Secondly, not all of the criteria are of equal importance. Susan thinks that what make a job jump out are salary, location, and potential for promotion – these, she decides, are the most important characteristics on which she wishes to focus. The remaining three criteria (benefits, schedule and work environment) are considered less important and can be used as supplementary

tie-breaking criteria when making the final decision between a few most promising options. Having too many criteria designated as of primary interest can lead to mediocre values for the best solutions if there are strong trade-offs between objectives. Hence, it is recommended to be selective about what to consider the top priorities.

Now focusing on the 14 remaining offers, Susan wants to further eliminate some offers that have at least one better option (that is as good for all criteria and strictly better for at least one criterion) based on the three most important criteria. After eliminating the inferior options, the remaining set comprises the Pareto front. For any offer on the Pareto front, there is no alternative that is strictly better for all of the three primary criteria. Hence the Pareto front offers an objective set of superior choices before considering the subjective choices of user priorities between criteria.

From the 14 offers remaining after eliminating based on the deal-breakers, 8 offers are identified on the Pareto front (shown in bold in Table 1). Any offer that is not on the front can be outperformed by a solution from the front. For example, offer 20 (not on the front) is beaten by offer 22 (on the front) since they tie for the same score on location, but offer 22 is strictly better for salary and potential for promotion. The pairwise scatter plots of the points on the Pareto front are shown in Figure 1. Among the three pairs of criteria, it can be observed that the most trade-off exists between salary and location, and there is least trade-off between salary and promotion. At the conclusion of this step, Susan has cut the number of choices to be considered from the original 25 down to a top 8. If she has identified her characteristics of interest and quantified the performance of each job on these characteristics, then this set of 8 jobs represent an indisputable set of superior choices, from which she can start to select based on her priorities and preferences. This more manageable set allows more careful consideration of the alternatives.

COMBINE

Next, in the COMBINE step, the Pareto front solutions are further examined to identify some leading contenders. In this stage, how one values the different characteristics and how one is willing to tolerate poor scores on one metric if the performance of other metrics is exceptional are important. Because multiple facets are simultaneously considered for capturing diverse attributes of the solution, we need to integrate the multiple metrics into the overall decision. There are different ways to achieve that. One way is to use the threshold approach, which tackles the individual criteria one-by-one based on their relative importance. Specifically, it may start with the most important criterion, determines the threshold below (or above) which we are unwilling to accept values. This eliminates a subset of the choices. The process is then repeated with the next most important criterion until all criteria are examined. The advantage of this approach is being able to work with the raw data. However, the determination of the thresholds is often quite subjective and the final decision can be highly sensitive to the choice of the thresholds. As the number of criteria considered grows, it becomes easy to end up with an empty set of contenders if ambitious thresholds are selected.

An alternative is to use the Utopia point approach [2] (which is closely related to the desirability function approach [4]). The idea is to rank all the points (offers) on the Pareto front based on their proximity to a Utopia point, which represents an ideal solution that simultaneously has best values for all criteria and often only exists in theory. Preferred solutions are those which are closest to the ideal solution. The proximity is measured based on combining different metrics for multiple criteria into an overall summary. This requires scaling different criteria values comparable scales and choosing appropriate weighting and metric form to combine different criteria together. Given the identified the Pareto front, this approach allows quick examination of different weighting, scaling and metric forms as well as their potential impacts on the decision. The following showcases a few graphical tools that can be used to evaluate the impacts of subjective choices and facilitate decision-making.

Figure 2 shows a mixture plot ([2]) which displays the best solutions (offers) for all possible weighting choices for certain selected scaling and metric forms. Here Susan decided to linearly scale the criteria values based on the range of values on the Pareto front. The worst criterion value on the front is scaled to 0 (least desirable) and the best value is scaled to 1 (most desirable). She has also chosen the metric in the form of $DF_i = w_s S_i + w_L L_i + w_P P_i$ for combining all three criteria, where S_i , L_i and P_i represent the scaled criteria values for salary, location, and potential for promotion for the i th job offer, and w_s , w_L , and w_P are the weights for these three criteria. This metric form does not place extra penalty on poor performance, and hence allows very good performance on one criterion to overcome very poor performance on another. In the mixture plot, each point in the triangle represents a weight combination. Vertices indicate all the weight on a single objective, edges consider two of the three objectives, while interior points consider non-zero weights for all three objectives. Different shades of gray distinguish different regions for different best solutions.

Among the 8 points on the Pareto front, 6 solutions are selected as best for some weight combinations. Offer 22 is optimal for 34% of the weights when salary and location are valued approximately equally important. Offer 8 is optimal for 25.5% of the weights when salary is considered more important than location. Offer 1 is optimal for 21.5% of the weights when location is valued more than salary. Offer 24 is optimal for 4.6% of the weights when salary and location are both important but salary is valued slightly more than the location. Offers 2 and 17 are best choices when promotion is considered less important.

After thinking carefully about the value of the three facets, Susan decides salary is more important than both the location and promotion, and she chose to weigh salary between 50%-80% and each one of the remaining two criteria receiving at least some consideration with at least 10% of the overall weight. The more focused weighting region is highlighted with the triangular area surrounded by the dash line in the mixture plot. Four offers are identified as best for at least some weight combinations within the focused region. Offers 8 and 22 are best for large areas of weights with offer 8 favoring more on salary. Offer 24 is optimal for a small slice of region with the weights partitioned around 7:3 between salary and location. Offer 17 is considered best for only a small region by the upper left edge of the triangular area and hence is very specific to a particular weight combination range.

Figure 3 is the trade-off plot [2] showing the relative performance of the criteria for different offers on the Pareto front. Offer 8 has the best salary and promotion scores, but is worst for location. Offer 2 has the best location and the worst salary and promotion. Offers 22, 24 and 17 are more balanced solutions with moderately good performance for all of the criteria. Among the three primary criteria, salary and location has the most trade-off and promotion has less trade-off with either salary or location. This matches with the pattern shown in the mixture plot where the solutions are less sensitive to changes in the weighting of promotion than the other two criteria.

SELECT

Recall that Susan started with 25 choices, and by specifying and applying her priorities, she has been able to reduce the number of choices down to 4 leading candidates. However, she still has some work to do, as she will only be able to accept a single job offer. To further compare the four best options selected in the mixture plot, in the SELECT step, Susan uses the synthesized efficiency plot [5] in Figure 4 to show the relative performance of the individual solution to the global optimal performance for different weighting choices. The white-gray-black scale is used for showing high to low synthesized efficiency as measured by the percentage of the optimal performance. Hence, a good solution would have as large a white area as possible in the weighting region of interest. For Susan's case, offer 8 has above 95% synthesized efficiency for around 75% of the triangular area and lower efficiency (at least 80%) around the bottom left

corner where location is given the second largest weight. Offer 22 has high efficiency in the bottom left triangular area and the lowest efficiency is above 85% when salary is weight close to 80%. Offer 24 has slightly larger high efficiency area than offer 22 and the lowest efficiency is above 90% within the focused weighting region. Offer 17 has overall darker color for a large portion of the triangular area and is highly efficient along the left edge of the triangular area when promotion is weighted less than the other two criteria. Overall, the four best offers can be categorized into two groups: offers 8 and 17 have best performance when salary is the dominating criterion but relatively poor performance when more weight is given to the other two criteria; offers 22 and 24 have pretty good performance (at least 85% efficient) for the entire weighting region of interest.

For an easier comparison, Susan can use the fraction of weighting space (FWS) plot [6, 7] to summarize the performance over the entire focused weighting region. Each curve for an offer shows for what fraction of the weights (horizontal axis) within the focused region the solution has synthesized efficiency at least as large as a certain percentage of the best possible performance (vertical axis). A flat curve near the maximum of 100% is ideal. Offer 8 has around 75% of the weights with synthesized efficiency above 93%. However, the performance drops quickly as it moves towards the worst case scenario. Offer 24 has smaller area of high efficiency but larger lowest efficiency across the focused region than offer 8. The FWS plot for offer 22 is slightly below the curve for offer 24, which indicates it has consistently smaller fraction of weights with certain level of performance. Offer 17 has consistently lower performance than offer 8 and its lowest worst efficiency is around 75%. Hence, among the two categories of options, offers 8 and 24 will be the top choice of each group. To choose between the two groups, if Susan wants the best performance for as large weighting area as possible, then she might want to choose offer 8; on the other hand, if she is worried more about having best possible performance for the worst case scenario, then offer 24 would be the best choice.

When there is a tie between a couple (or a few) most promising choices, an effective way of choosing between these options is to compare their performance on the supplementary criteria, which are the benefits, schedule, and work environment in the job-search example. In Susan's case, the values for the three supplementary criteria for job offers 8 and 24 are (7,4,6) and (7,8,7), respectively. Hence, offer 24 is preferred when the supplementary criteria are considered. If there is no obvious winner among the few choices based on the supplementary criteria, then a similar REDUCE-COMBINE-SELECT procedure can be applied to make a final decision based on the supplementary criteria.

At the conclusion of the process, Susan has identified an overall best choice and now knows which job offer she wishes to accept. Not only has she sequentially eliminated non-contenders and less desirable solutions, but having a structured graphical approach to evaluating and considering alternatives has led to a deeper understanding of the choices and greater comfort with the final job offer. The job that she has selected has a salary of \$81K (near the top end of the range of offers she had), and scores a perfect 10 on potential for promotion. She had to sacrifice some on the location (6 out of 10), but the three supplementary criteria of benefits (7/10), schedule (8/10) and work environment (7/10) are solidly in her comfort zone for what she was seeking.

Conclusions

We have described a new DMRCs process for structured decision making, which mirrors the approach of the DMAIC process which has become so popular within Lean Six Sigma. By dividing a complex often unstructured process into distinct steps, we hope to have made the task of balancing multiple competing objectives less daunting. A few final thoughts:

1. While the DEFINE and MEASURE steps are easily described for our example and look straightforward, this part of the process holds the key to success for all subsequent stages. Without a properly defined goal for the decision, and without high quality data on which

- to base all later steps, the entire process could give nonsensical results. Investing in articulating the right problem to focus on and feeling confident in the believability of all the criteria scores for all of the alternatives are essential to a quality decision!
2. The use of the Pareto front in the REDUCE step plays a fundamental role in eliminating non-contenders without imposing any subjectivity and decision-maker preference about how to scale or compare the different criteria. We think that postponing the insertion of subjectivity can be quite helpful to give a common launching point, particularly for discussion when teams are involved in the decisions.
 3. We would like to emphasize that the process and the specific tools used within the subjective steps can be separated. In talking with decision-makers, we have found that there are many different ways to consider the trade-offs between alternatives. The tools that we describe have worked well for a number of groups that we have worked with, but they are certainly many alternatives for how to evaluate a smaller number of choices based on diverse criteria. If other tools feel like a better fit, we offer the suggestion that ways to visualize the data be included in the process. Graphical displays provide an engaging way of studying the choices and help facilitate deeper discussions about which solution is best.

The keys to successful decision-making lies in focusing on the right criteria, having solid quantitative measures on which to base choices, eliminating silly options that are inferior to other choices, and finding a way to meaningfully and fairly compare the “apples and oranges” of the different dimensions of the problem. The DMRCs process can guide the decision-maker through a sequence of steps to reach a justifiable final choice.

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Table 1: Data for the job search example. The criterion “term” is categorical with two levels (short vs. long). The “salary” is measured in thousands of dollars per year. The remaining five criteria are all measured in a 0 -10 scale with 0 for the worst and 10 for the best. The entries shown in gray are excluded considering the deal-breaker criteria (Short term or Salary<65k). The 8 offers identified on the Pareto front are shown in bold.

Job #	Term	Salary (\$K/year)	Location	Potential for Promotion	Benefits	Schedule	Work Environment
1	Long	70	7.5	10	7	8	7
2	Long	66	8.5	5	8	10	3
3	Short	80	6	10	9	8	5
4	Long	75	7	7	9	8	9
5	Long	42	9.5	7	6	8	10
6	Long	55	9	7	6	8	4
7	Long	68	8	7	7	10	6
8	Long	84	4	10	7	4	6
9	Long	78	6	5	10	8	5
10	Long	72	7	5	8	8	6
11	Short	90	3	10	8	4	8
12	Short	86	4.5	10	10	8	7
13	Long	64	7	7	7	10	10
14	Long	69	6	5	9	8	9
15	Long	73	7	7	10	8	8
16	Long	62	9	7	7	10	9
17	Long	83	6	7	8	8	6
18	Short	79	5	7	9	10	8
19	Long	57	7	7	9	8	8
20	Long	76	6.5	7	7	8	7
21	Long	63	7	5	8	10	8
22	Long	80	6.5	10	8	8	9
23	Long	65	8	7	7	10	5
24	Long	81	6	10	7	8	7
25	Long	57	7	7	6	8	8

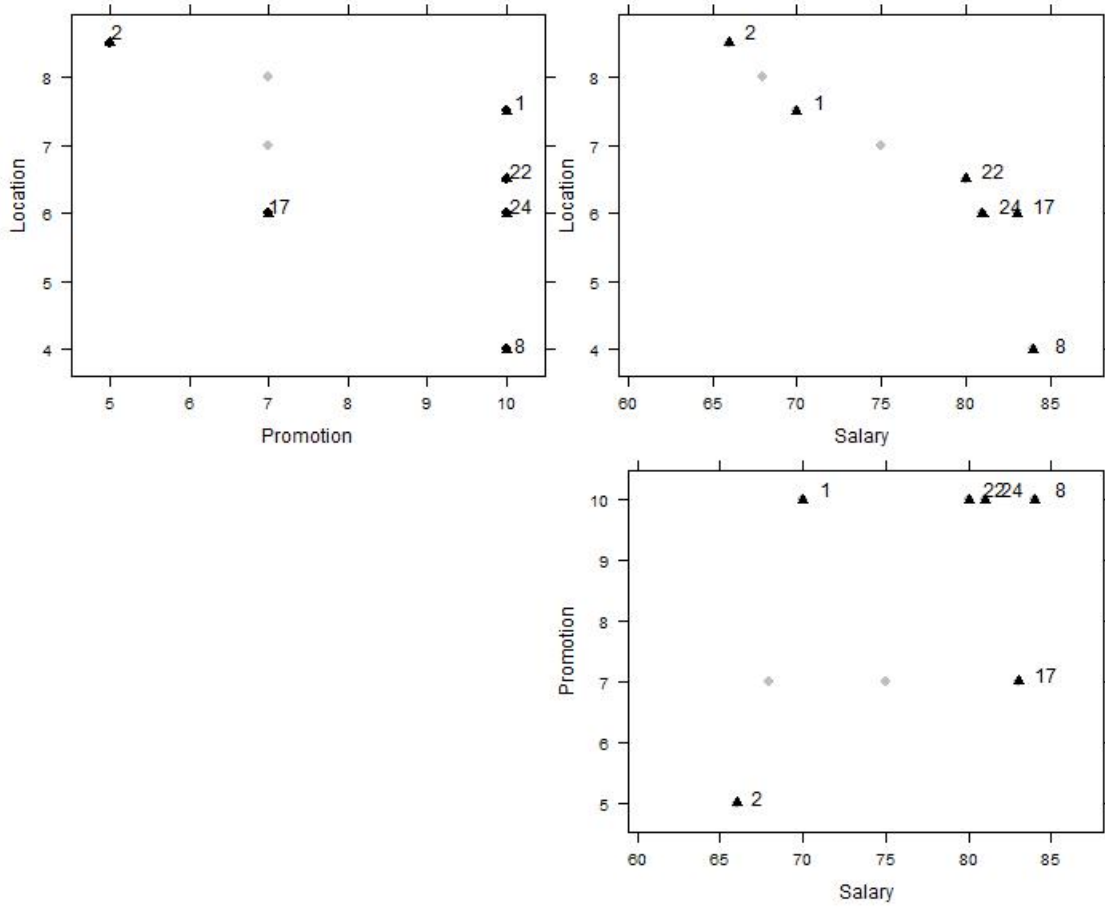


Figure 1: Pairwise scatter plots for the 8 job offers on the Pareto front. The 6 offers selected as best for at least one set of weight combination are highlighted in black symbols. The remaining offers that belong to the front but not selected in the mixture plot are shown in gray symbols.

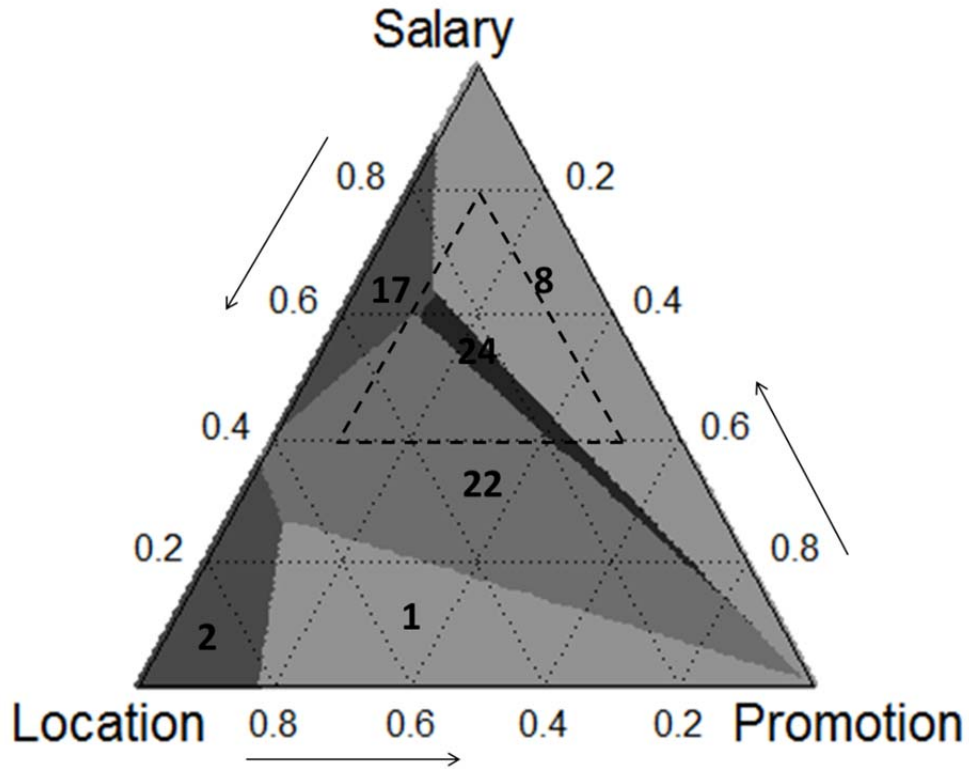


Figure 2: Mixture plot for showing the six best job offers for different weighting choices. The focused weight region with $0.5 \leq w_S \leq 0.8$, $0.1 \leq w_L \leq 0.4$, and $0.1 \leq w_P \leq 0.4$, that is of primary interest to Susan is shown as the triangular area surrounded by the dash lines.

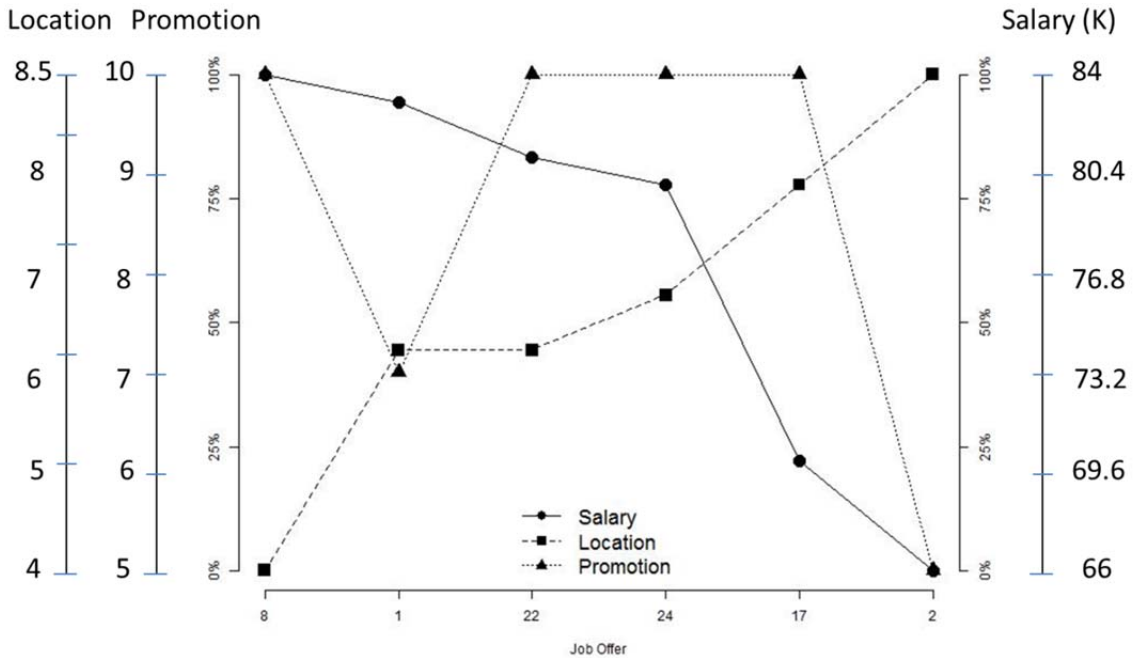


Figure 3: Trade-off plot for the six leading offers selected using the Utopia point approach with the additive desirability function.

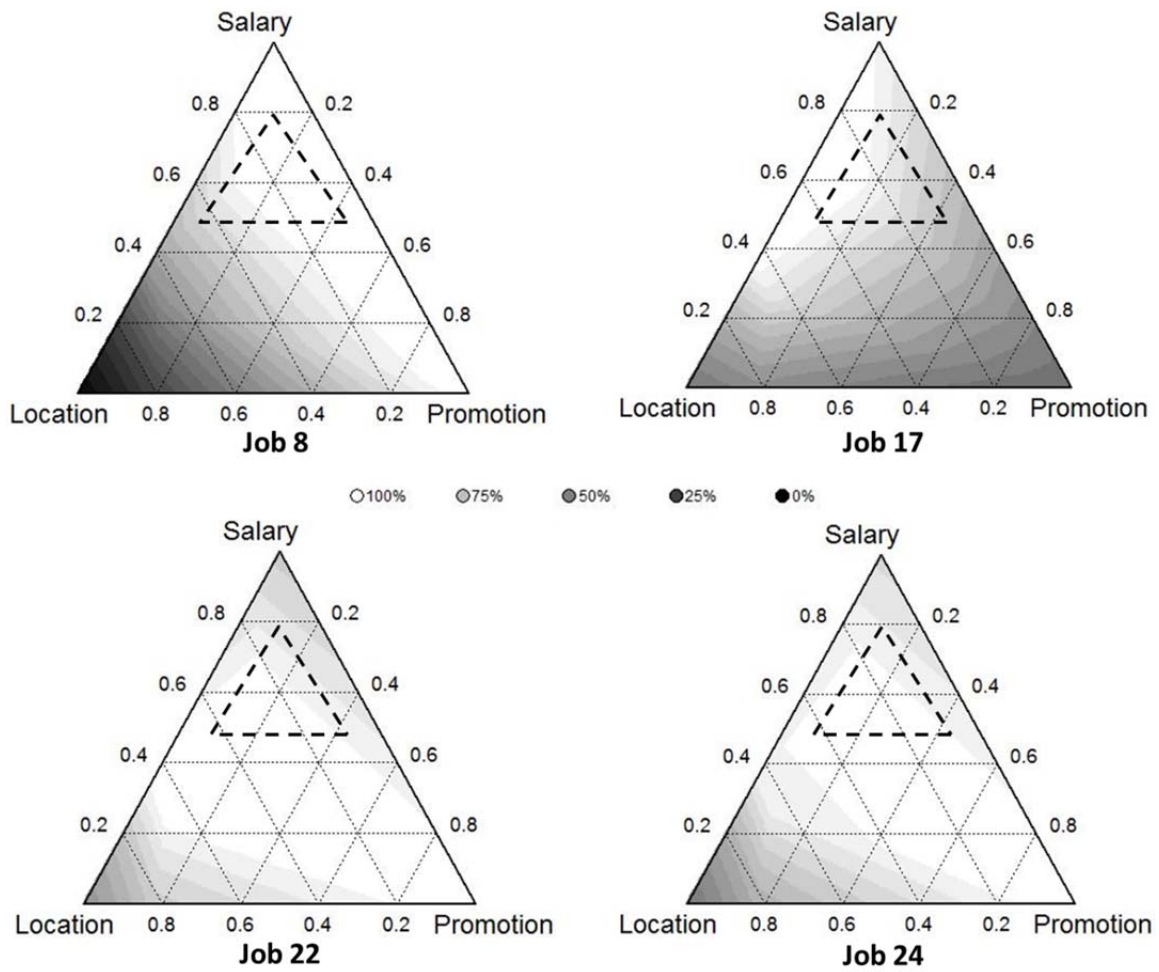


Figure 4: Synthesized efficiency plot for the four best job offers identified in the mixture plot.

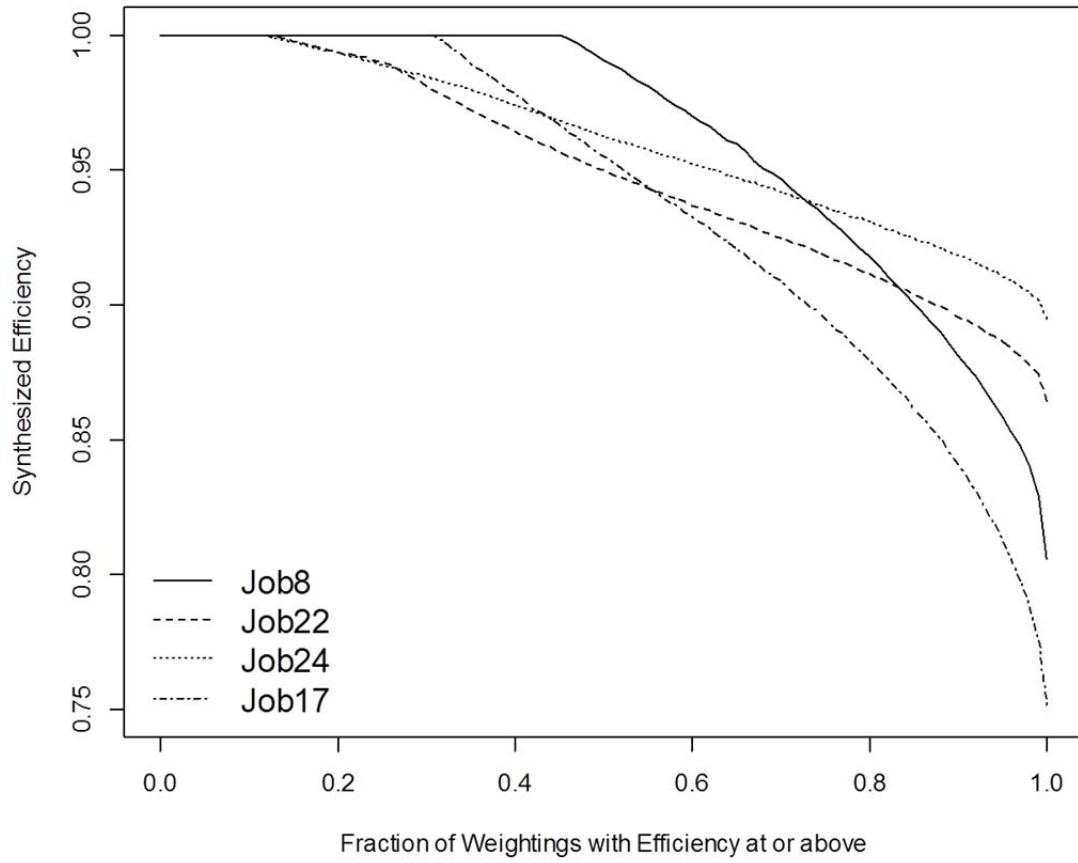


Figure 5: Fraction of weighting space (FWS) plot for the four best job offers identified in the mixture plot.