Heuristics for two extensions of basic troubleshooting

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A simple troubleshooter example

\[ q_1 = 0.20 \]
\[ q_2 = 0.25 \]
\[ q_3 = 0.40 \]
\[ q_4 = 0.15 \]

\[ p_1 = 0.45 \]
\[ p_2 = 0.65 \]
\[ p_3 = 0.55 \]
“Basic Troubleshooting” – Assumptions:

✓ **Perfect repair:** Relaxed in FVJ’s talk.

✓ **No questions:** Heuristic approach in FVJ’s talk. However, we maintain the assumption in our work.

✓ **Single fault:** Kept throughout as a realistic assumption in our domain.

✓ **Fixed cost:**
If the costs of the TS-steps do not depend on the previous TS-steps the domain has fixed costs. Otherwise, we say the domain has *conditional cost.*

✓ **Independent actions:**
If there exists a pair of actions \((A_i, A_j)\) such that \(A_i\) can remedy at least one of the faults that \(A_j\) handles we say that the model has *dependent actions.* If no such pair exists the domain has independent actions.
“Basic Troubleshooting” – Main result

Define the efficiency of action \( A_i \) as

\[
ef(A_i \mid \epsilon) = \frac{P(A_i = y \mid \epsilon)}{C_i}
\]

**Proposition 1.** Under the “Basic Troubleshooting – assumptions” (No questions, Single fault, Independent actions and Fixed costs) it holds that:

The sequence \( S = \langle A_1, \ldots, A_N \rangle \) minimizes the ECR if and only if

\[
ef(A_1 \mid \emptyset) \geq ef(A_2 \mid \emptyset) \geq \ldots \geq ef(A_N \mid \emptyset)
\]
Conditional cost

Definition 1. By conditional cost we mean that the cost of an action depends on the sequence of actions performed so far, that is, the user can change the cost $C_i$ by performing actions in a given sequence before doing $A_i$.

If, e.g., we have performed the partial sequence $S = \langle A_1, A_2, \ldots, A_{i-1} \rangle$, then the cost of the next action, $A_i$, say, is given by a known function,

$$C_i = f_i(S) .$$

We simplify this general situation by enforcing a one-step memory, so that

$$C_i = g_i(i - 1)$$

for some known function $g_i(\cdot)$.
The “Cluster-framework”

Two scenarios are considered:

✔ **With inside information:**
  
  We can at all times check if the problem is solved.

✔ **Without inside information:**
  
  We must perform finalization work to check if the problem is solved.
The “Cluster-framework”, cont’d.

\[
e_{f}(\text{Cluster} \mid e) \overset{\text{def}}{=} \max_{\mathcal{J}} \frac{\sum_{i: A_i \in \mathcal{J}} P(A_i = y \mid e)}{C_0 + \sum_{i: A_i \in \mathcal{J}} \gamma_i + C_\infty}
\]

where maximization of \( \mathcal{J} \) runs over all subsets of actions in the cluster.
Calculations “without inside information”

\[
\frac{p_{\text{Solved}}}{C_0 + \sum_\kappa \gamma_\kappa + C_\infty} \geq \frac{p_\ell}{\gamma_\ell}
\]
Empirical results “without inside information”

a) One cluster of size 9
   and one atomic action

b) One cluster of size 5
   and 5 atomic actions.
Failure of the simple calculation scheme; “with inside information”

Consider a system of 3 actions, where $A_1$ and $A_2$ are clustered together. Let $C_0 = C_\infty = 5.5$.

<table>
<thead>
<tr>
<th>Action</th>
<th>$P(A_i = y)$</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>.25</td>
<td>$\gamma_1 = 5$</td>
</tr>
<tr>
<td>$A_2$</td>
<td>.25</td>
<td>$\gamma_2 = 17$</td>
</tr>
<tr>
<td>$A_3$</td>
<td>.5</td>
<td>$C_3 = 32.9$</td>
</tr>
</tbody>
</table>

By calculating the cluster efficiency as proposed we find

$$ef(Cluster) = ef(A_1) = .0156 > ef(A_3) = .0152 ,$$

so that we would perform $A_1$ before $A_3$. This gives $ECR = 45.2$. However, the optimal sequence is $\langle A_3, \{A_1, A_2\}\rangle$ with $ECR = 45.15$. 
Dependent Actions

Definition 2.
We say that a troubleshooting system with the single fault assumption has dependent actions whenever there are two actions \( A_i \) and \( A_j \) such that \( P(A_i = y, A_j = y) > 0 \).

Since \( ef(A_2) = .65 > ef(A_3) = .55 > ef(A_1) = .45 \), we know that only the strategies \( \langle A_2, A_1, A_3 \rangle, \langle A_2, A_3, A_1 \rangle, \) and \( \langle A_3, A_1, A_2 \rangle \) are possible.
What the local efficiencies cannot tell

\[
\text{obef}(A_i | \epsilon) = \frac{P(A_i = y | \epsilon)}{C_i - P(A_i = n | \epsilon) \cdot \text{VOI}(A_i = n | \epsilon)}
\]

\[
\text{VOI}(A_i = n | \epsilon) = \text{ECR}(\epsilon) - \text{ECR}(A_i = n, \epsilon)
\]
Myopic calculation of ECR

1. Calculate myopic ECR given $\mathbf{e}$:
   (a) Order actions by efficiencies given $\mathbf{e}$.
   (b) Calculate ECR for the sequence,
   $$ \hat{ECR}(\mathbf{e}) = \sum_{j=i+1}^{n} C_j \cdot P(A_i = n, \ldots, A_{j-1} = n | \mathbf{e}) $$

2. Calculate myopic ECR given $\{\mathbf{e}, A_i = n\}$:
   (a) Order actions by efficiencies given $\{\mathbf{e}, A_i = n\}$.
   (b) Calculate ECR for that sequence,
   $$ \hat{ECR}(\mathbf{e}, A_i = n) = \sum_{j=i+1}^{n} C_j \cdot P(A_{i+1} = n, \ldots, A_{j-1} = n | \mathbf{e}, A_i = n) $$

This gives an approximation of $\text{VOI}(A_i = n | \mathbf{e})$. 
Conclusions

✔ We have proposed a heuristic method to handle a subset of conditional cost problems by grouping actions into ‘clusters’.
The heuristic works fairly well, with an ECR about 2% higher than the optimal.

✔ We have proposed a heuristic method for handling dependent actions, by incorporating simple value of information-calculations into the efficiency calculations.

We implemented two different approaches, with varying degree of computational overhead. The heuristic methods offer strategies that reduce the ECR by from 15% (myopic) to 25% (Shannon) compared to the results of the SACSO tool. The comparison was performed on an example network with 80 actions.