A decision-analytic approach for the optimal allocation of resources to diagnostic testing and treatment

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Context

- A patient either has or does not have a disease

- Treating patients gives benefit but has personal and societal costs
  1. Treating a sick patient (true positive)
  2. Treating a healthy patient (false positive)
  3. Not treating a sick patient (false negative)
  4. Not treating a healthy patient (true negative)

- Diagnostic tests provide information about the patient’s health
  • Tests are not fully reliable (false positives, false negatives)
  • Tests can be costly (e.g., genetic testing)
  • Diagnosis is often based on multiple tests
Identifying effective test-treatment strategies

- Individual level
  - Which tests should be carried out?
  - In which order is it optimal to carry them out?
  - When should one stop testing and decide on a treatment action?
Identifying effective test-treatment strategies

- Population level
  - How to divide the population of patients into different segments?
  - How to allocate resources to each segment?
  - Which tests and treatments to carry out to each segment?

- Important allocation decisions
  - Testing vs. treatment
  - High risk patients vs. low risk patients
  - Preventive care vs. reactive care
  - Cardiovascular diseases vs. cancer
Departure point

- Tests often used in combinations and sequences

- Resources often limited

- The benefit of a population is maximized instead of an individual patient or subpopulation

- Our contribution: a method for identifying optimal test-treatment strategies and optimal allocation between testing and treatment
Our decision-analytic approach

- Patient has a prior probability of having the disease (risk)

- Patient can be tested using multiple tests and testing stages
  - Probability of disease is updated based on test results using Bayesian methods
  - Tests have direct costs and they improve the accuracy of diagnosis

- Patient can be treated using a single treatment
  - Treatments have direct costs and health-related and financial outcomes

- Test-treatment strategies are measured by their expected

  Net benefit = (Health outcomes) × λ − (Financial outcomes) − (Direct costs)
Problem is solved in two stages

1. Identify non-dominated pathways
   - i.e. pathways in which the expected net benefit cannot be increased without increasing direct costs
   - for each prior probability of disease (0%, 1%, ..., 100%)
   - for variety of direct cost levels
   - using dynamic programming

2. Choose the pathways which maximize the net benefit of the whole population
   - using known population distribution
   - at given level of direct costs
   - using mixed integer linear programming
Illustrative example

- Four treatment actions
  - Expected net benefits are known

- Four tests
  - Each has two possible results
  - Conditional probabilities of obtaining the results are known
  - Costs are known

- One testing stage

### Conditional net benefits

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No disease</th>
<th>Disease</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>No treatment</td>
<td>10 000 €</td>
<td>0 €</td>
<td>0 €</td>
</tr>
<tr>
<td>Treatment 1</td>
<td>9 000 €</td>
<td>4 000 €</td>
<td>100 €</td>
</tr>
<tr>
<td>Treatment 2</td>
<td>8 000 €</td>
<td>6 000 €</td>
<td>300 €</td>
</tr>
<tr>
<td>Treatment 3</td>
<td>6 000 €</td>
<td>7 000 €</td>
<td>800 €</td>
</tr>
</tbody>
</table>

### Conditional probabilities of test results

<table>
<thead>
<tr>
<th>Test</th>
<th>Test result</th>
<th>No disease</th>
<th>Disease</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Negative</td>
<td>0.85</td>
<td>0.32</td>
<td>150 €</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>0.15</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Negative</td>
<td>0.65</td>
<td>0.15</td>
<td>200 €</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>0.35</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Negative</td>
<td>0.90</td>
<td>0.10</td>
<td>400 €</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>0.10</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Negative</td>
<td>1.00</td>
<td>0.00</td>
<td>800 €</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>0.00</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>
Computation

- First, non-dominated pathways for each prior risk group

- Second, pathways for each population group such that the expected population-level net benefit is maximized
Results – optimal pathway

- Optimal pathway of decisions
  - for each prior probability
  - for each relevant direct cost level

- Decision support tool for practice, micro level decision making
Results – optimal segmentation

- Optimal segmentation of patients
  - for each direct cost level

- Basis of care recommendations
Results – optimal allocation
Results – expected net benefit of optimal strategy

- Expected net benefit of a population at different cost levels
- Marginal net benefit of an investment
- Can be compared with other investments
- Support for macro level managerial decisions
Future topics

- Real data application
- Extensive sensitivity analysis for the value of $\lambda$
- Incorporating time dynamics and changing state of health