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

July 28, 2016

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ORAHS 2016

Systems Analysis Laboratory

Context

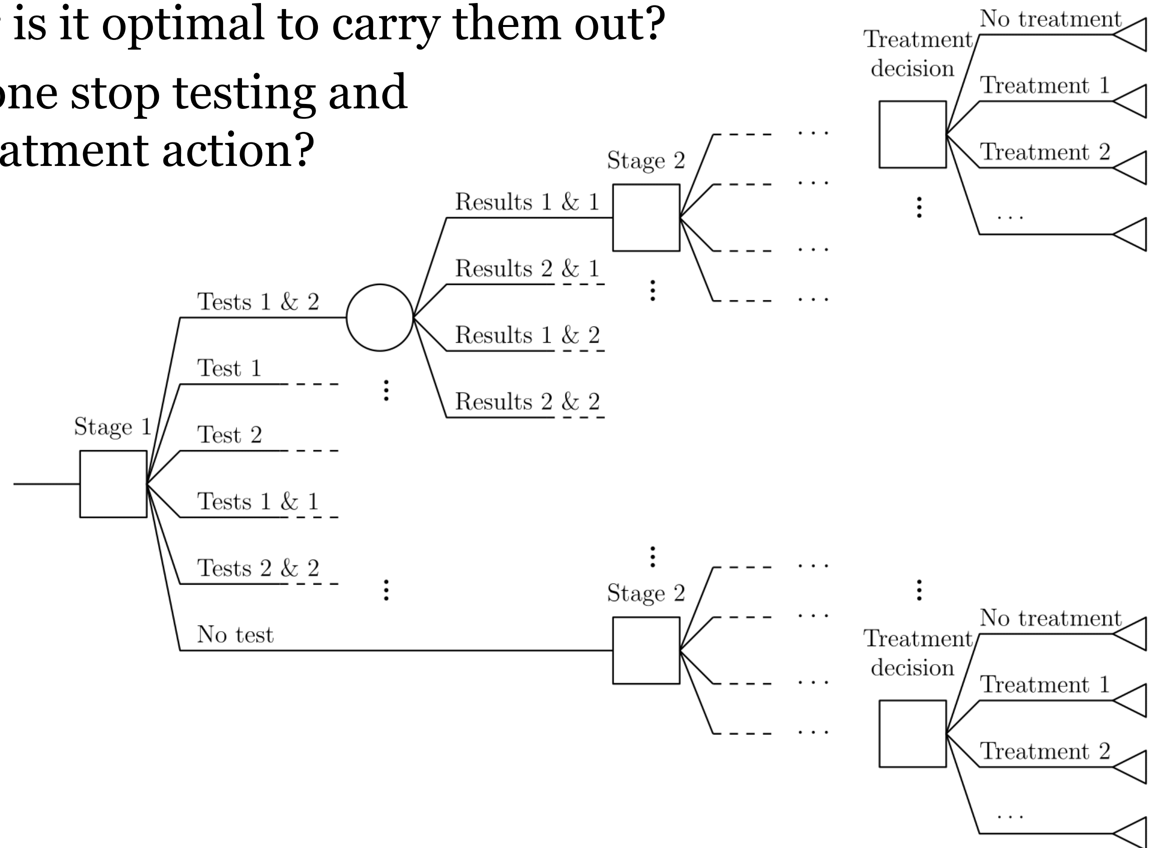
- A patient either has or does not have a disease

- 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

$$\text{Net benefit} = (\text{Health outcomes}) \times \lambda \; - (\text{Financial outcomes}) \; - (\text{Direct costs})$$

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

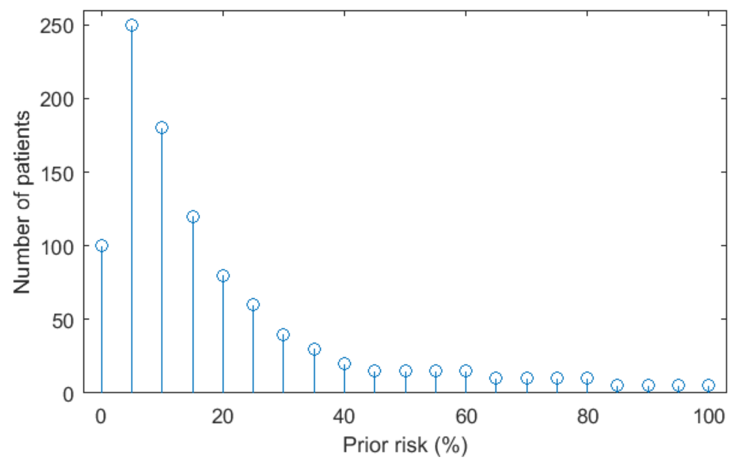
Treatment	No disease	Disease	Cost
No treatment	10 000 €	0 €	0 €
Treatment 1	9 000 €	4 000 €	100 €
Treatment 2	8 000 €	6 000 €	300 €
Treatment 3	6 000 €	7 000 €	800 €

Conditional probabilities of test results

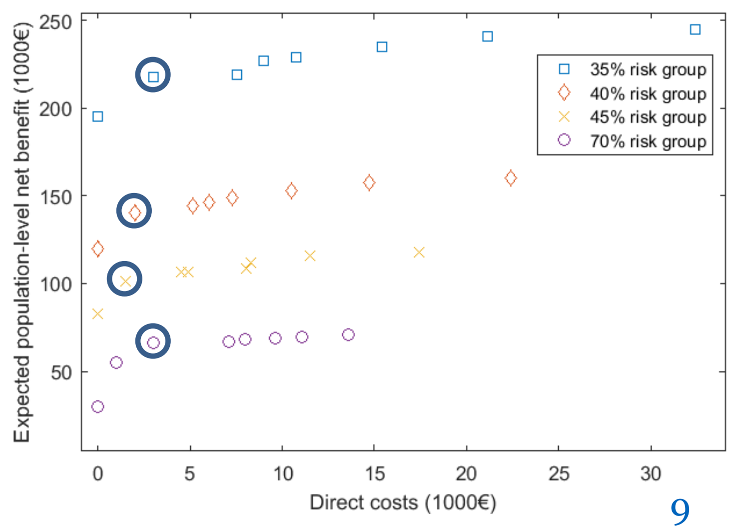
Test	Test result	No disease	Disease	Cost
1	Negative	0.85	0.32	150 €
	Positive	0.15	0.68	
2	Negative	0.65	0.15	200 €
	Positive	0.35	0.85	
3	Negative	0.90	0.10	400 €
	Positive	0.10	0.90	
4	Negative	1.00	0.00	800 €
	Positive	0.00	1.00	

Computation

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



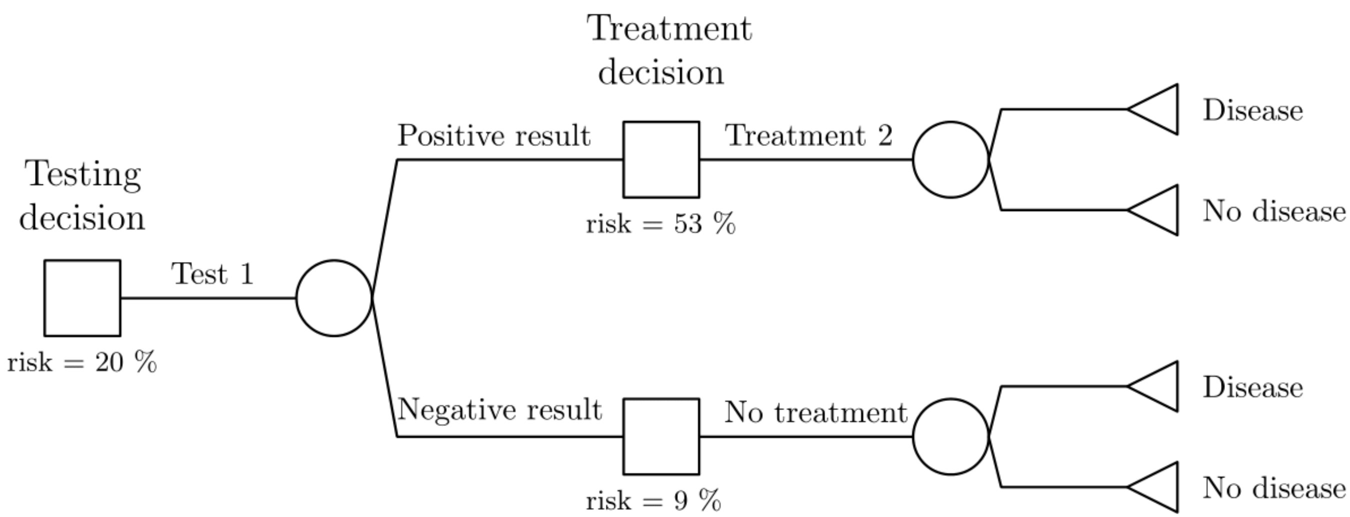
- Second, pathways for each population group such that the expected population-level net benefit is maximized



Results – optimal pathway

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

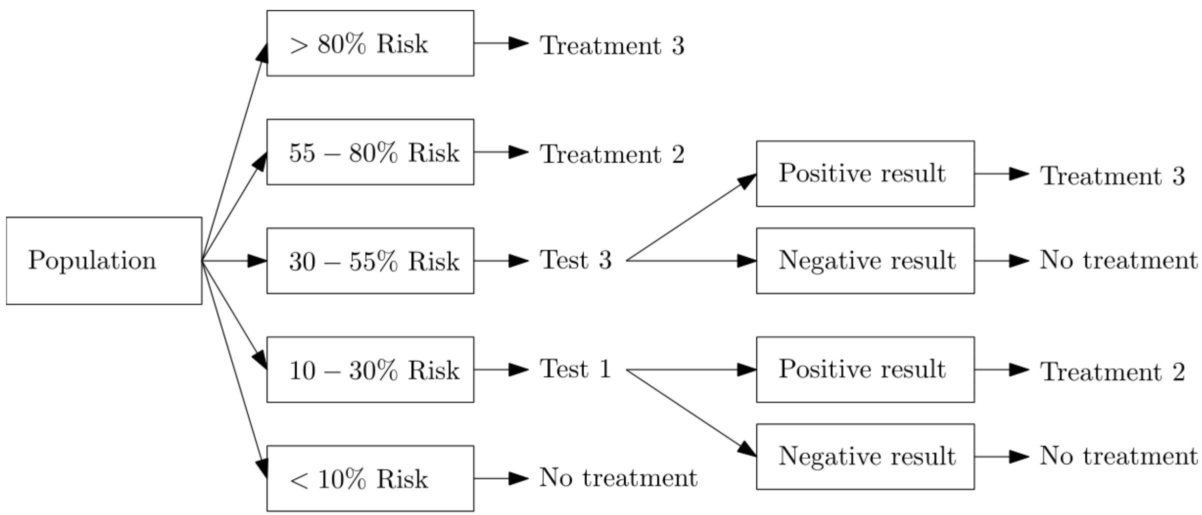
- Decision support tool for practice, micro level decision making



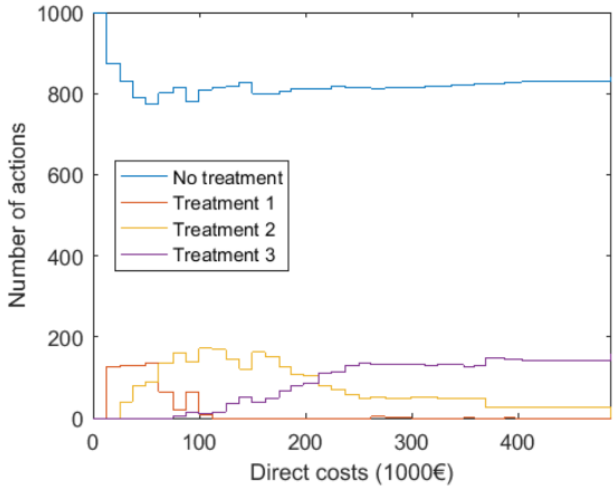
Results – optimal segmentation

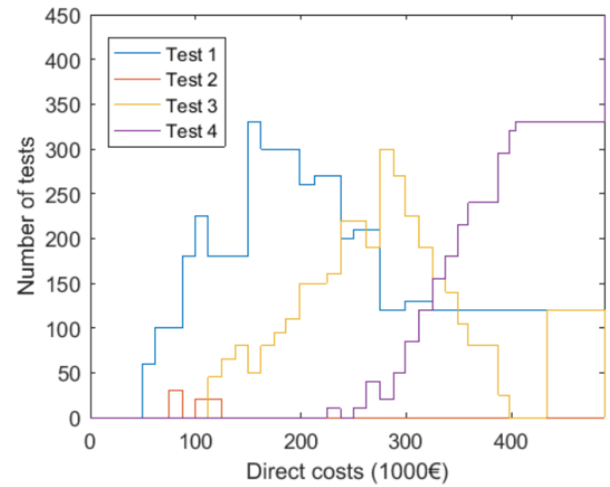
- Optimal segmentation of patients
  - for each direct cost level

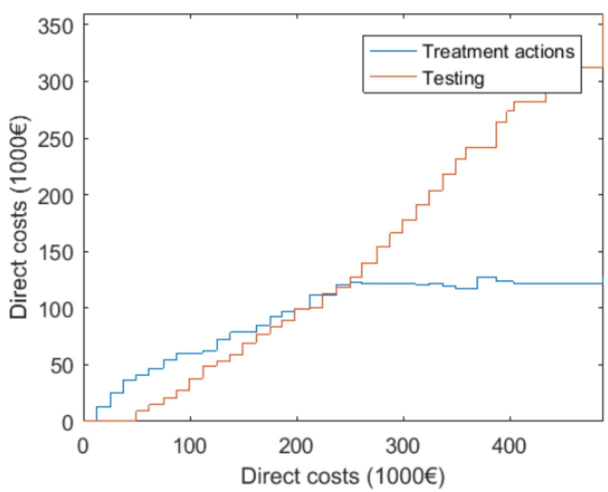
- Basis of care recommendations

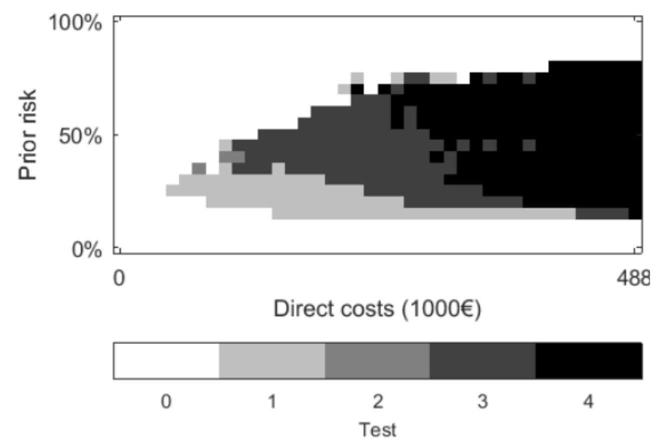


Results – optimal allocation



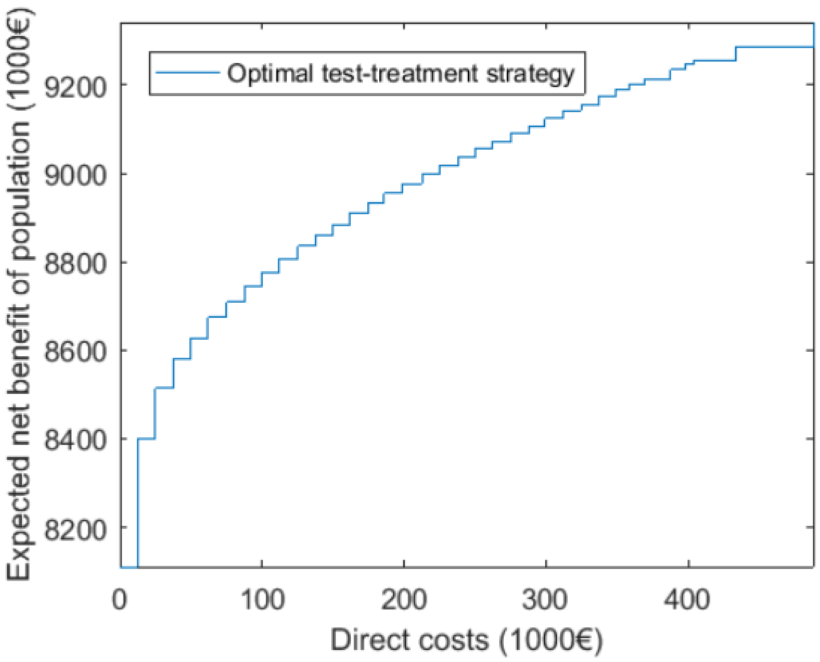






Results – expected net benefit of optimal strategy

- 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 λ
- Incorporating time dynamics and changing state of health