Geospatial Visual Analytics:

Visual Techniques for Decision Support

Fraunhofer Institut Intelligente Analyse- und Informationssysteme IAIS

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http://geoanalytics.net

The concept of Decision Support

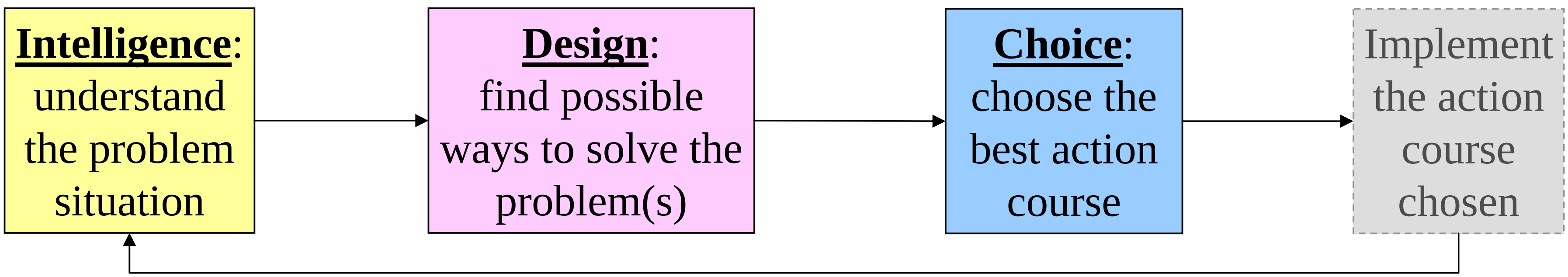
Embraces a wide variety of approaches and technologies intended to support any stage or aspect of human decision-making process:

- collection, management and analysis of relevant data and information;
- design of possible solutions and planning of appropriate actions;
- evaluation of alternative solutions and choice of optimum solutions;
- prediction of future situation developments and consequences of this or that action;
- collection, management, and utilisation of relevant expert knowledge, experiences and lessons learnt;
- documentation and substantiation of decision made;
- communication and collaboration in the process of decision making

Decision-making process (after H. Simon)

collect and integrate data;
explore the data, identify
problems and opportunities

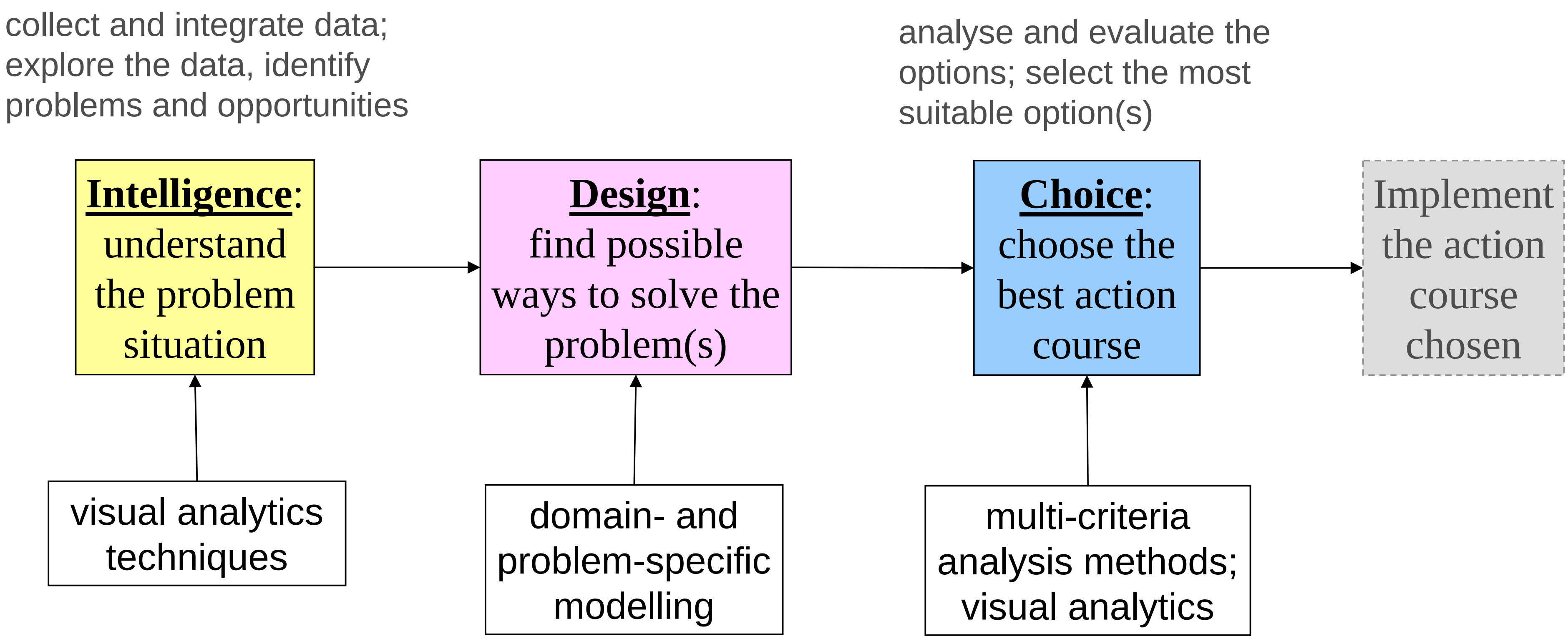
analyse and evaluate the
options; select the most
suitable option(s)



Do the results correspond to what was expected?

How did the situation change? Is the chosen action course still valid?

Support to the stages of the decision-making process



Multi-criteria decision analysis

- Support decision makers in choosing appropriate options on the basis of multiple conflicting criteria (typically expressed as numeric attributes)
- Example: give limited funding for improving health care to one or a few counties which are most in need

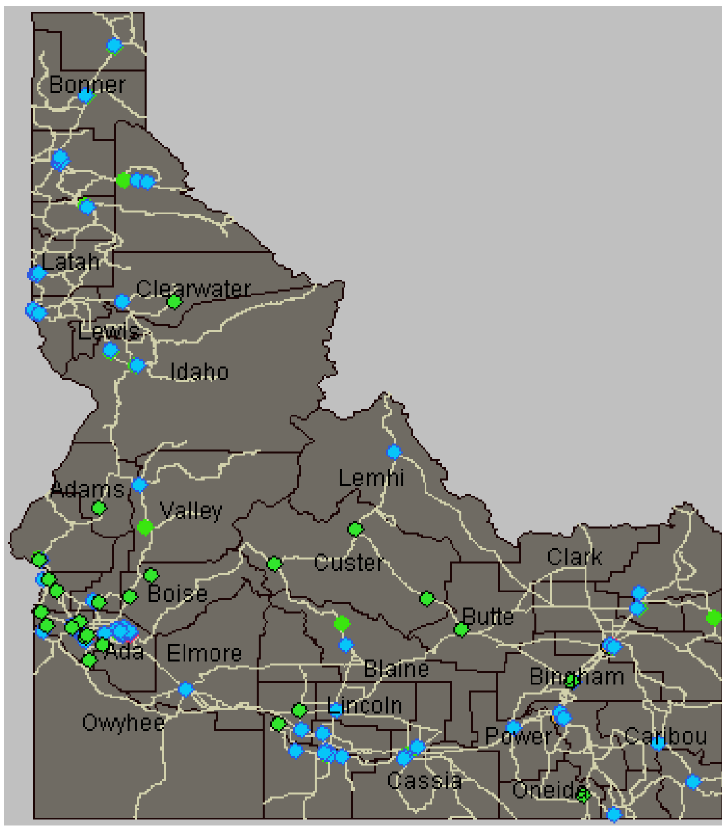


Table view: County.csv

	N of estimated unmet visits	% of population on medicare	Low-weight birth rate	Burden on on-call providers	Population in >35 miles from hospital	Emergency room visits
Jefferson	18078	10.23	4.71	4.03	0	11226.5
Twin_Falls	14733	17.80	6.63	2.98	100	18115.0
Latah	14168	20.72	7.38	2.55	100	15448.5
Madison	8606	13.74	5.21	2.46	1600	3841.5
Fremont	4614	24.32	5.29	3.10	0	4451.5
Jerome	3607	13.79	6.46	7.00	100	0.0
Payette	2994	15.79	6.74	7.00	429	0.0
Clark	2614	20.44	4.94	7.00	0	0.0
Blaine	2546	24.26	7.15	2.06	0	1670.0
Camas	2002	19.58	5.04	2.28	0	2058.5
Shoshone	1837	18.50	4.12	2.46	175	714.0
Bingham	1622	17.87	3.68	1.62	100	0.0
Washington	996	25.61	7.85	7.00	423	0.0
Lemhi	833	23.17	4.98	3.88	100	347.0
Clearwater	653	17.45	2.99	5.00	2335	0.0
Ada	-1018	16.00	5.44	3.15	100	1836.0

Sort by: N of estimated unmet visits | Descending | ☑ TableLens | ☐ condensed | Attribute...

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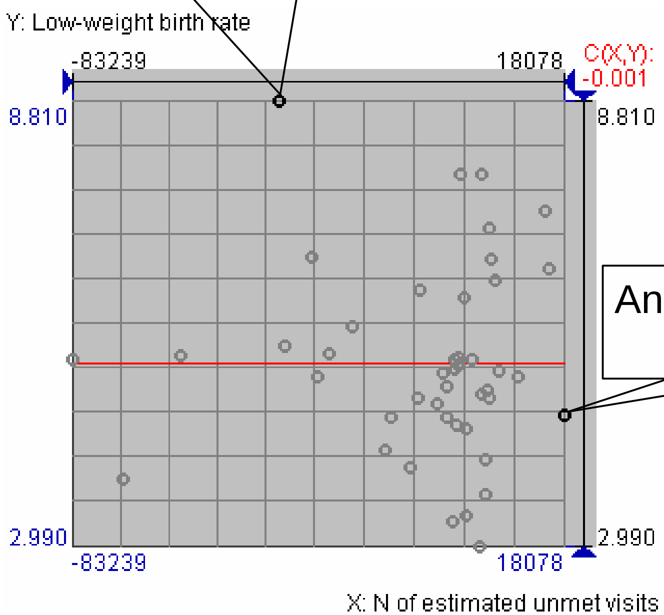
Trade-offs between criteria

- The choice is not easy and straightforward even in case of just two criteria…

This county has the highest rate of low-weight births but low estimated number of unmet visits of doctors



An opposite situation is in this county

There is no ideal candidate for receiving funding, i.e. a county with the highest values of both attributes.

It is necessary to look for a suitable trade-off: an option with reasonably high (but not necessarily extreme) values of both attributes.

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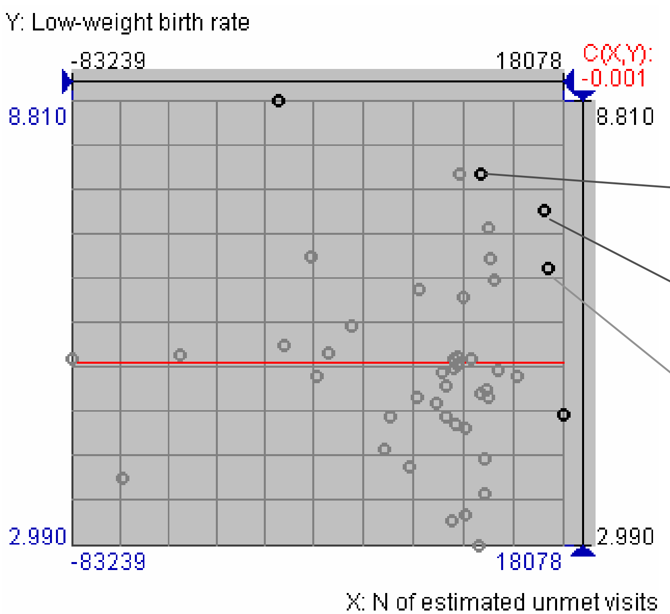
Pareto-optimality

- Introduced by Vilfredo Pareto, an Italian economist
- An option is *Pareto-optimal* in terms of two or more criteria if there is no other option that has better values of all these criteria.
- It is reasonable to choose a Pareto-optimal option. However, there may be multiple such options.



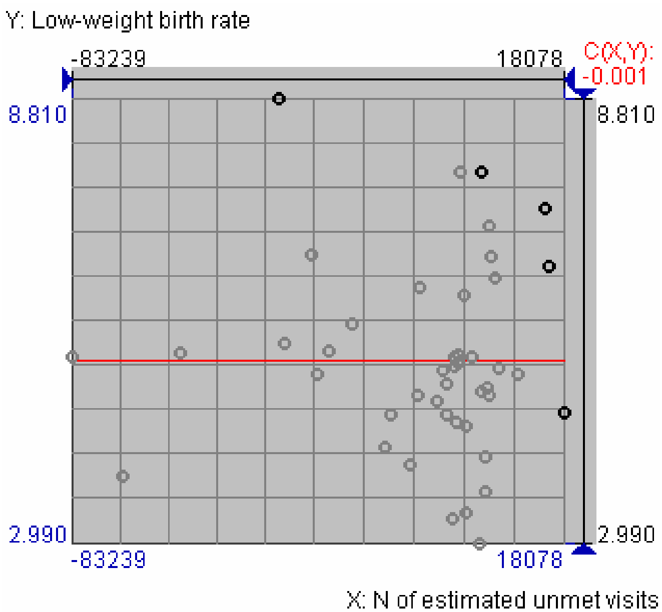
All points highlighted in black represent Pareto-optimal options.
The choice will depend on the relative importance of the criteria.

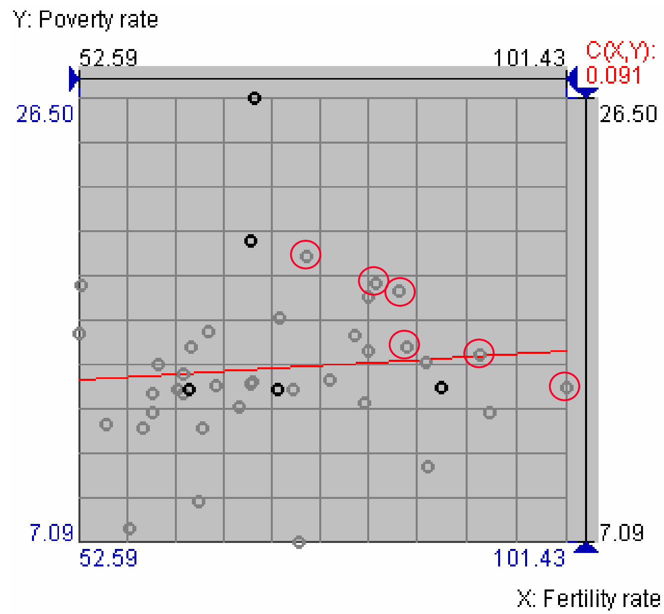
This option is preferred if low-weight birth rate is considered to be more important

This option is preferred if N of estimated unmet visits is given more importance

This option is only slightly better in terms of N of estimated unmet visits but much worse in terms of low-weight birth rate

More than 2 criteria



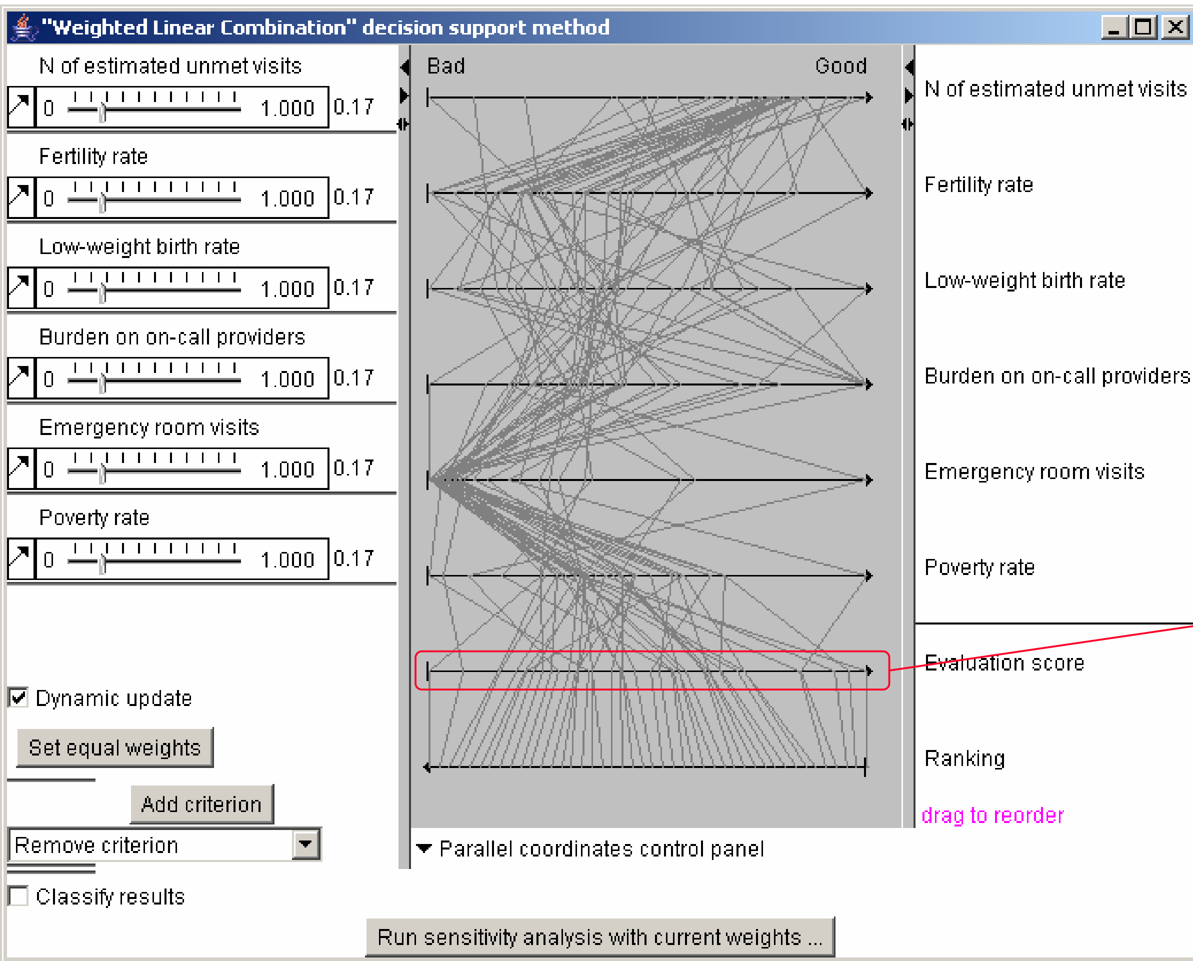


The options we have considered as good candidates according to 2 criteria may not seem so good when we involve more criteria.

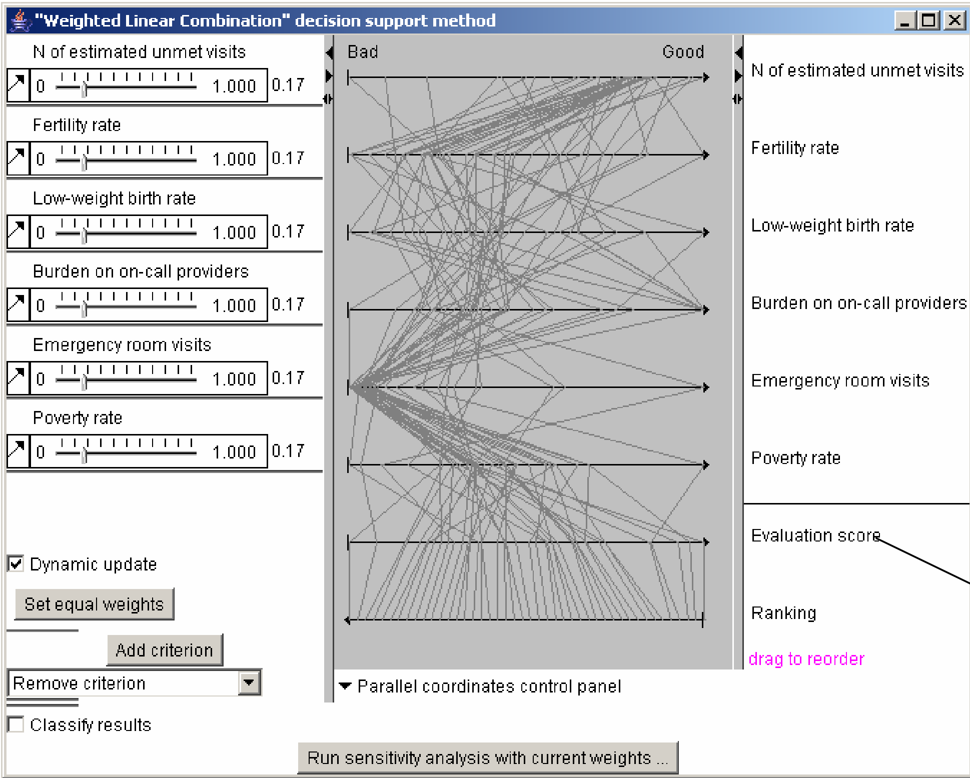
The set of Pareto-optimal options increases with adding each new criterion, and it gets tricky to see the trade-offs and make the choice.

There is a need in a computational tool capable to integrate multiple criteria into unified scores or ranks taking into account possibly different importance of the criteria.

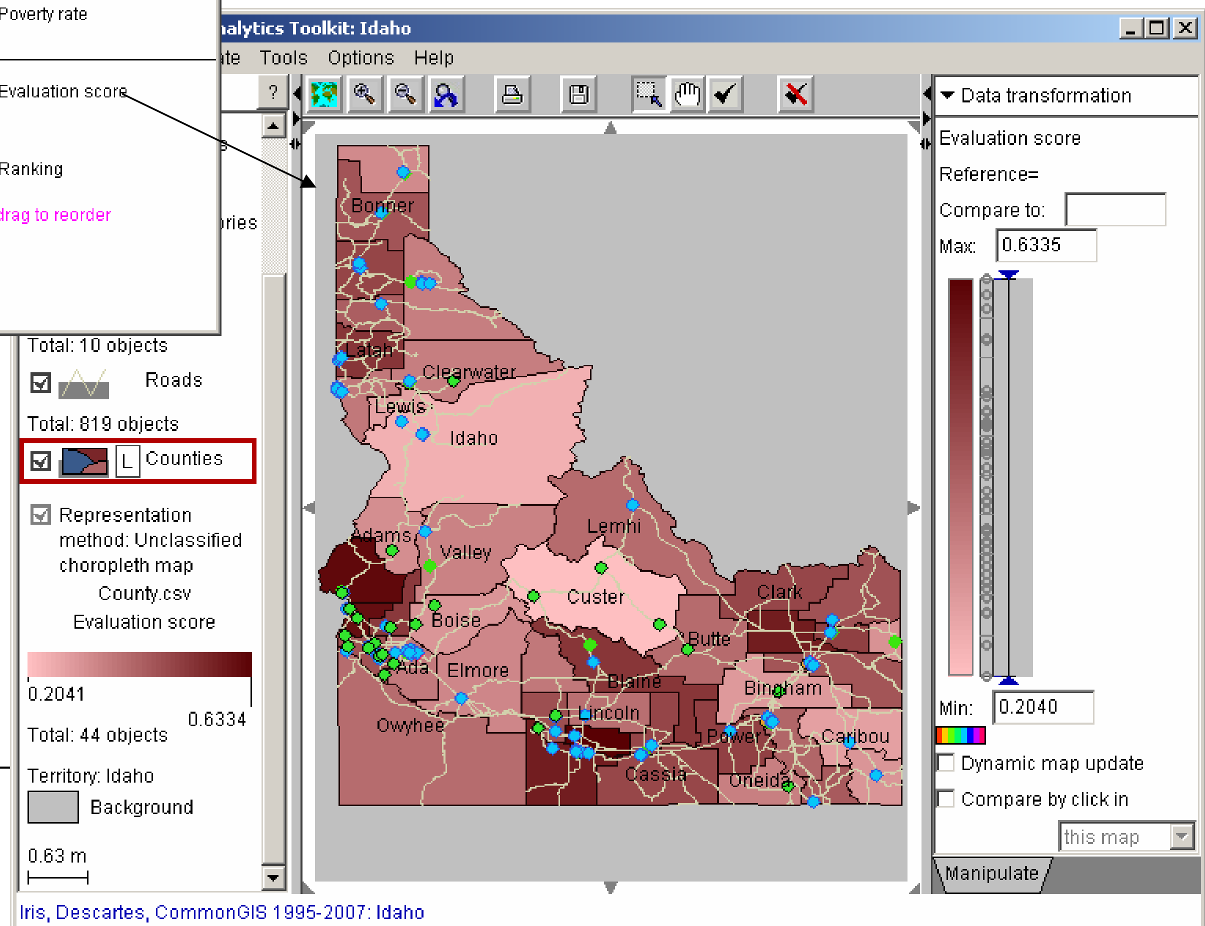
Example of a tool



Computed integrated evaluation scores

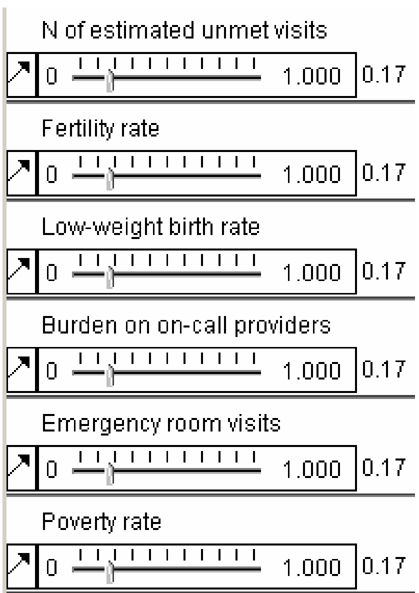


The computed scores are represented on the map



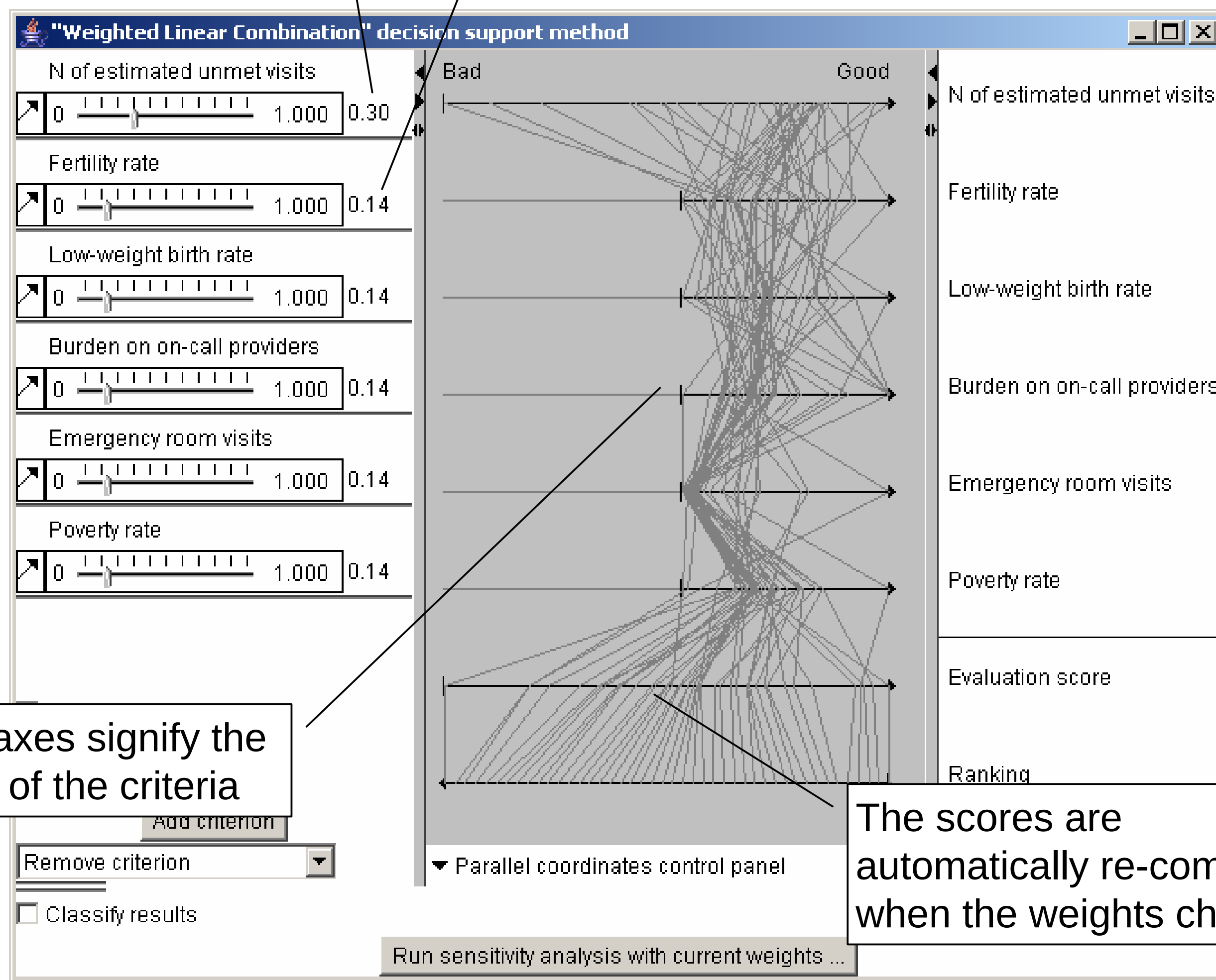
Expressing different importance of criteria

The relative importance of the criteria is specified by assigning them different *weights*



We have given this criterion a higher weight.

The weights of the other criteria have been automatically reduced (the sum must be 1.0).



The lengths of the axes signify the relative importance of the criteria

The scores are automatically re-computed when the weights change

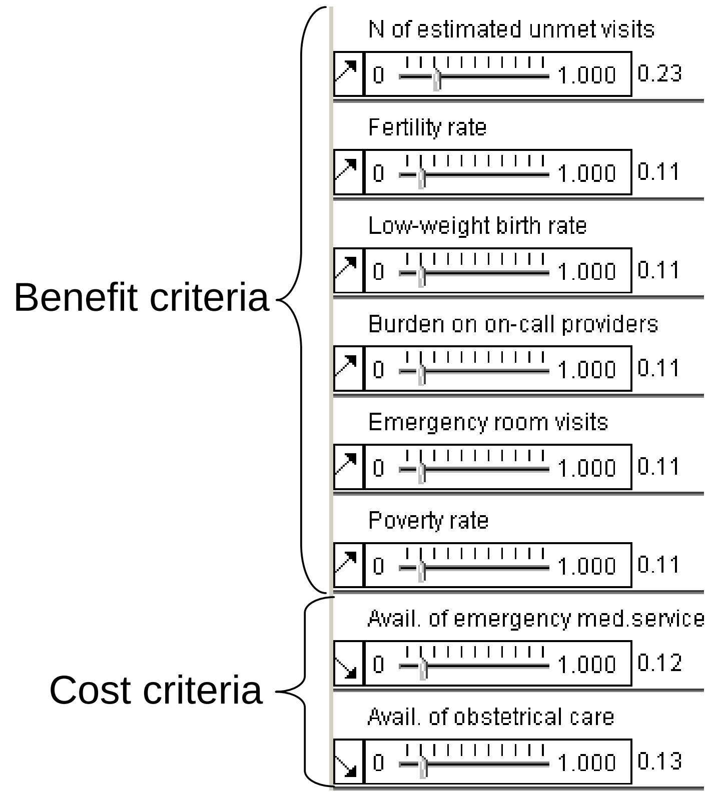
Computing the integrated scores

- Weighted linear combination: $score^i = w_1 * x^i_1 + w_2 * x^i_2 + \dots w_n * x^i_n$
  - $w_1, w_2, \dots, w_n$ – weights of criteria 1, 2, …, n
  - $x^i_1, x^i_2, \dots, x^i_n$ – normalised values of option i in terms of the criteria 1, 2, …, n
- "Ideal Point": a more sophisticated algorithm taking into account the distances of the options to the best and the worst theoretically possible options
  - Hwang, C. L., and Yoon, K., 1981, Multiple Attribute Decision Making: Methods and Applications (Berlin: Springer-Verlag).

Benefit and cost criteria

2 major types of criteria: benefit and cost

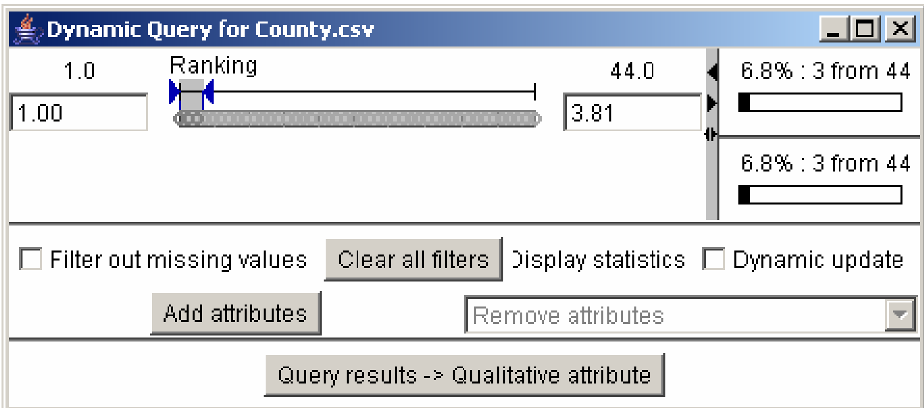
- <u>Benefit criterion</u>: higher values are more suitable
- <u>Cost criterion</u>: lower values are more suitable
- Other types of numeric criteria can be transformed to one of these
  - E.g. the middle value is more suitable: transform the original values into the distances from the middle value.

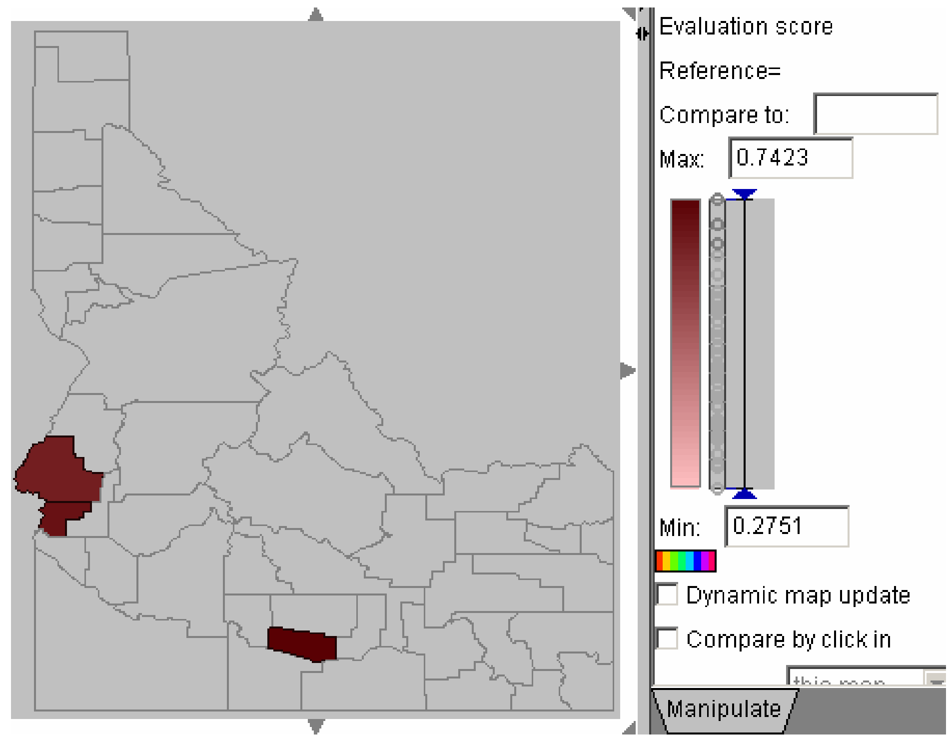


The techniques for criteria integration take into account the "direction" of the criteria (benefit or cost)

Impact of the criteria weights

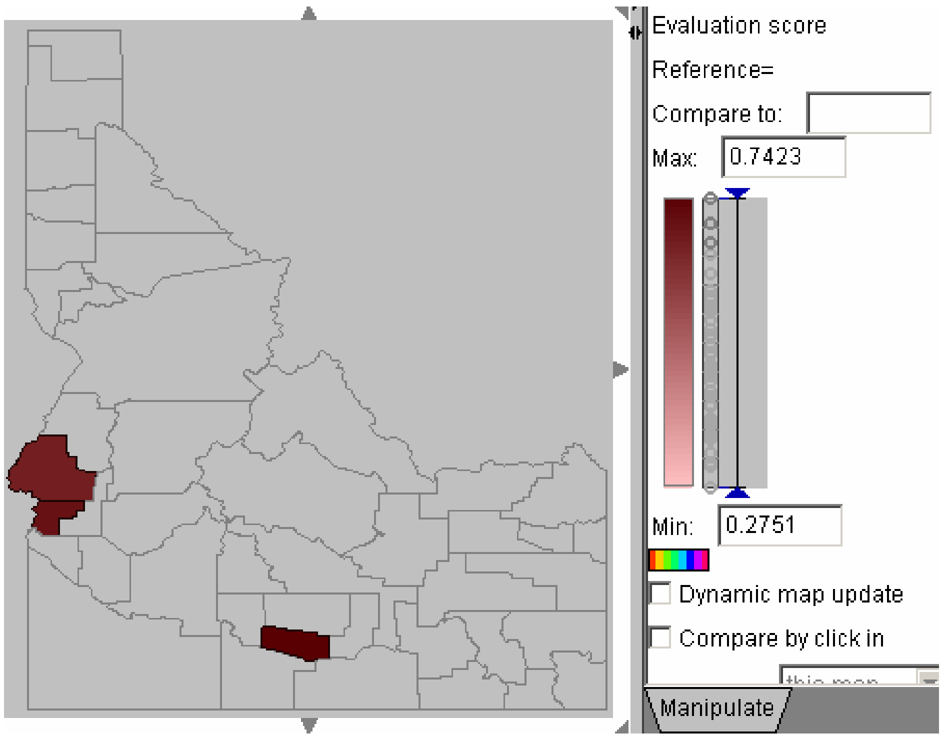
With the help of the dynamic query tool we select 3 topmost-ranked options (with the highest scores)



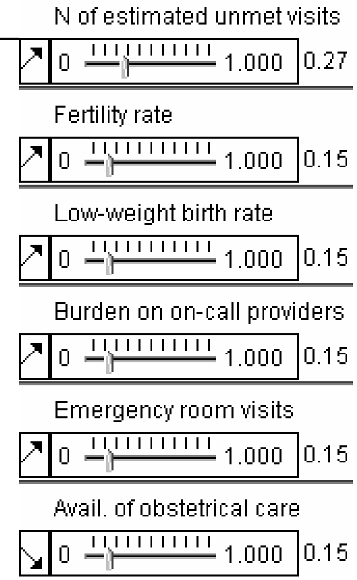


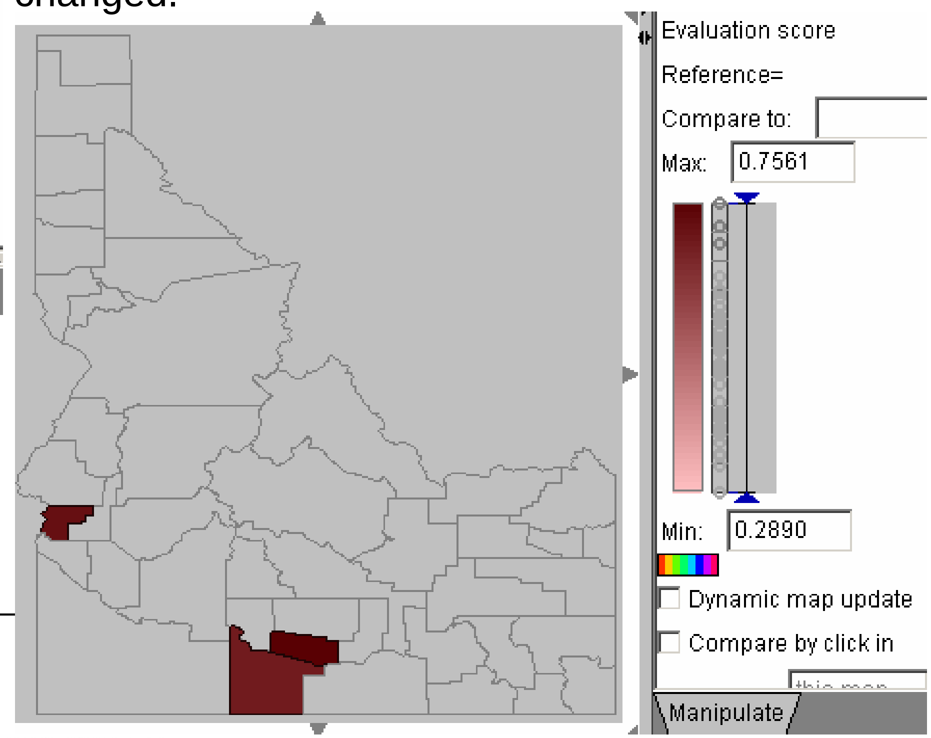
When we change the weights of the criteria, the scores and the ranks are re-computed, and the query condition is applied to the updated values.

These 3 counties where the best choices when all criteria had equal weights



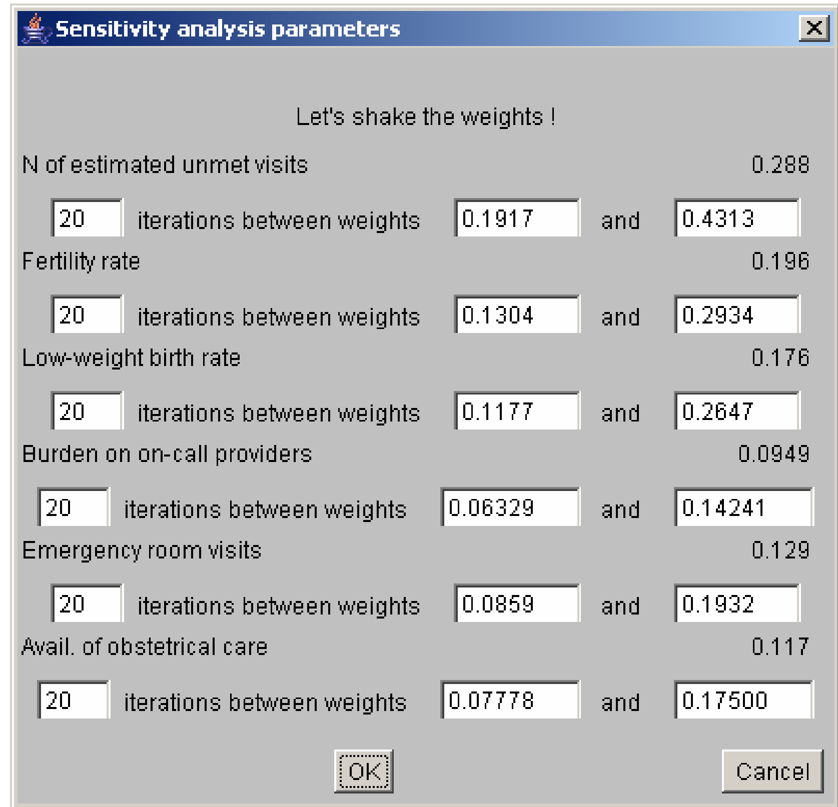
When we have increased the weight of “N estimated unmet visits”, the set of 3 topmost-scoring options has slightly changed.

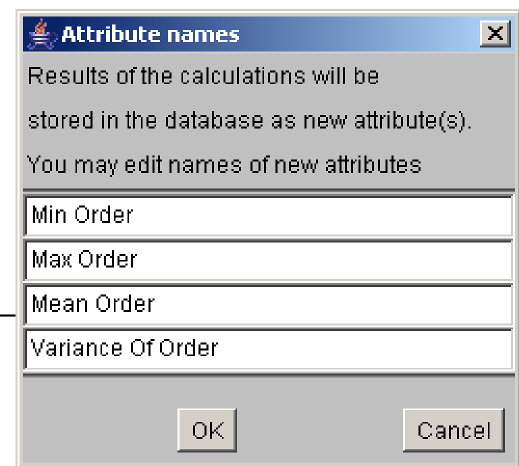


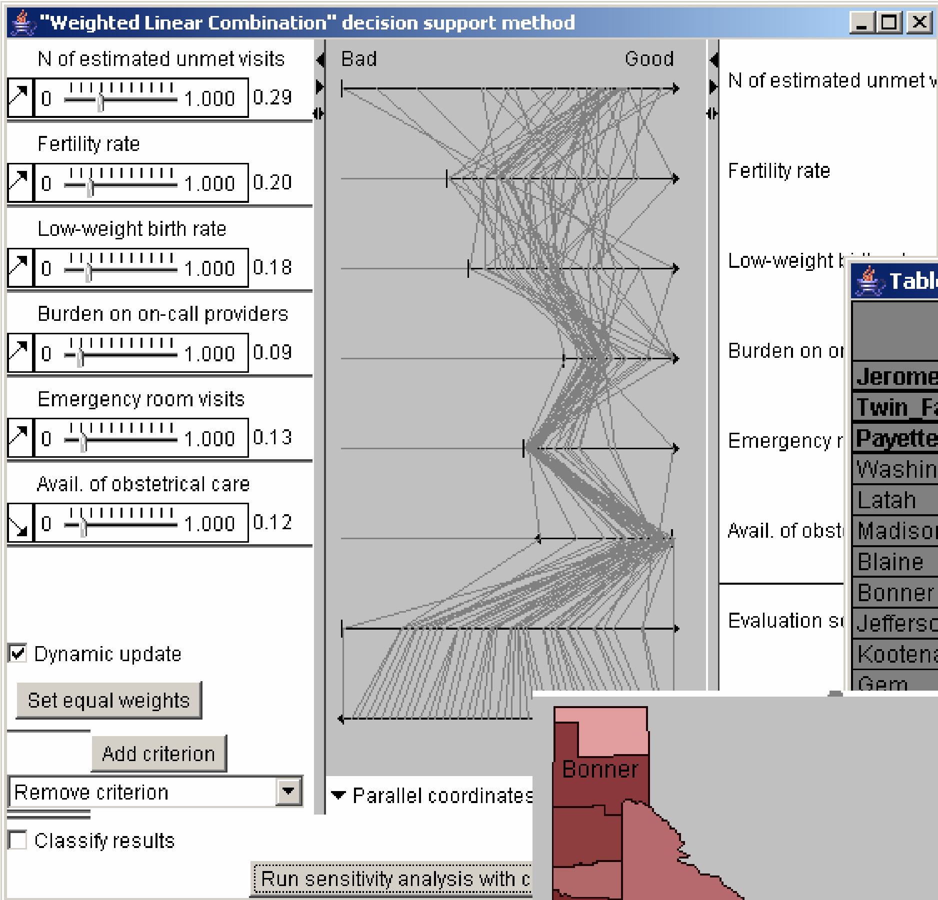


Sensitivity analysis

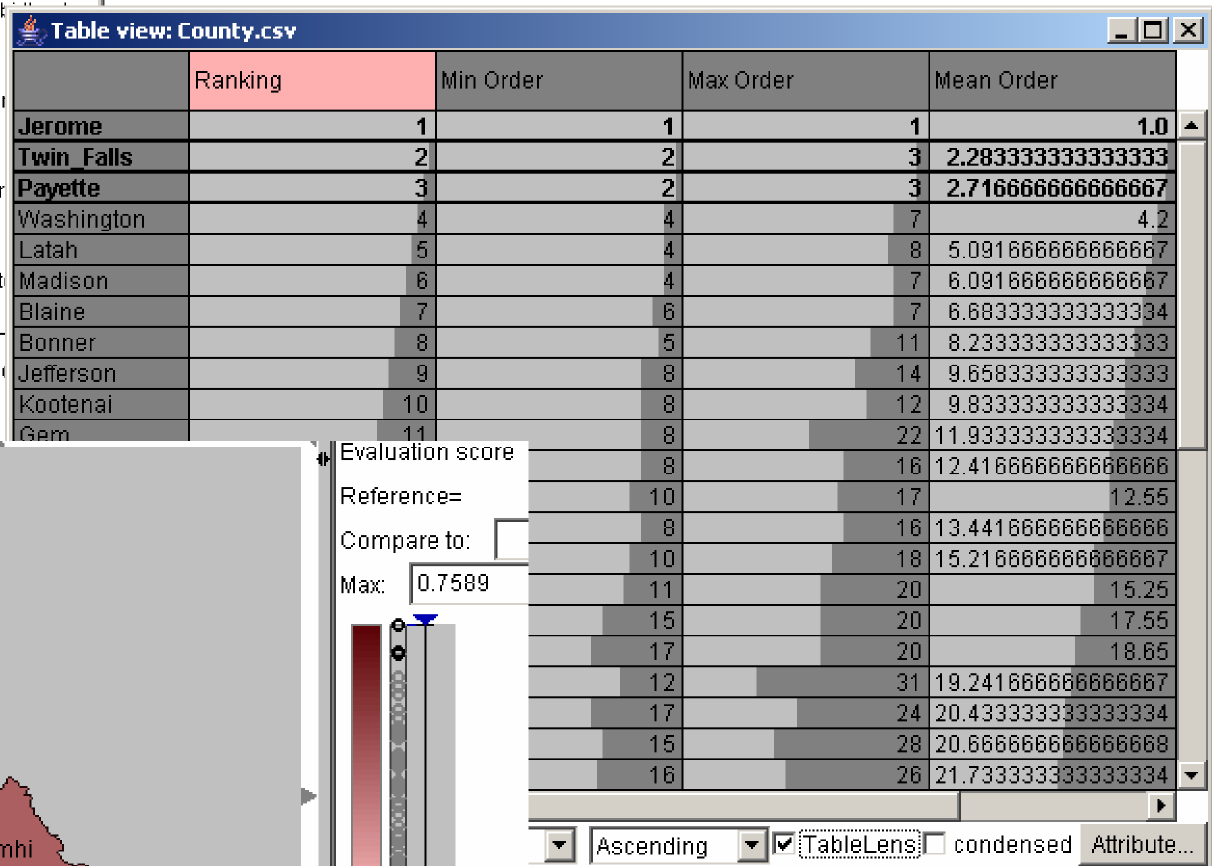
- After we have expressed our ideas about the relative importance of the criteria in terms of their weights, we want to make sure that the solution we obtain is robust, i.e. slight modifications of the weights will not have a dramatic impact.
- Interactive sensitivity analysis: move the sliders and observe the effect (may be time consuming and not very reliable).
- Computational sensitivity analysis: the system varies the weights around the chosen weights and provides useful statistics of changes, which is added to the table describing the options

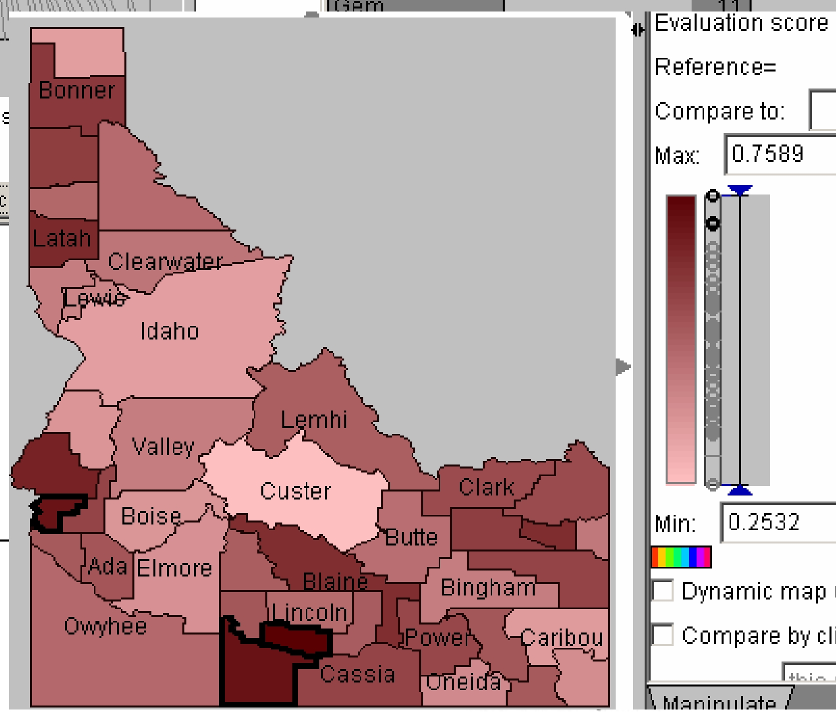






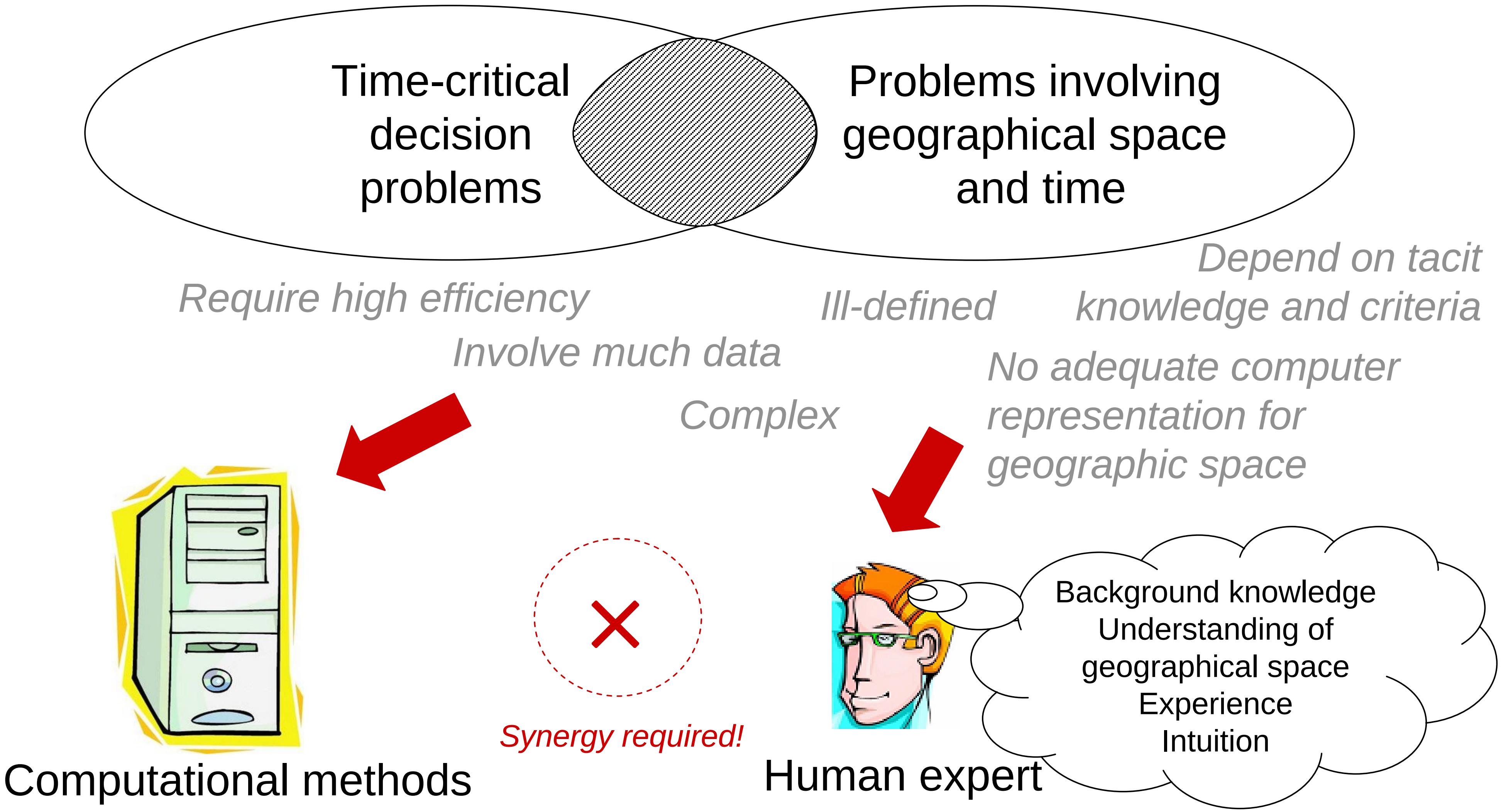
We see that Jerome, Twin Falls and Payette were the topmost candidates for all weight combinations tested by the system. Moreover, Jerome had always the highest rank.



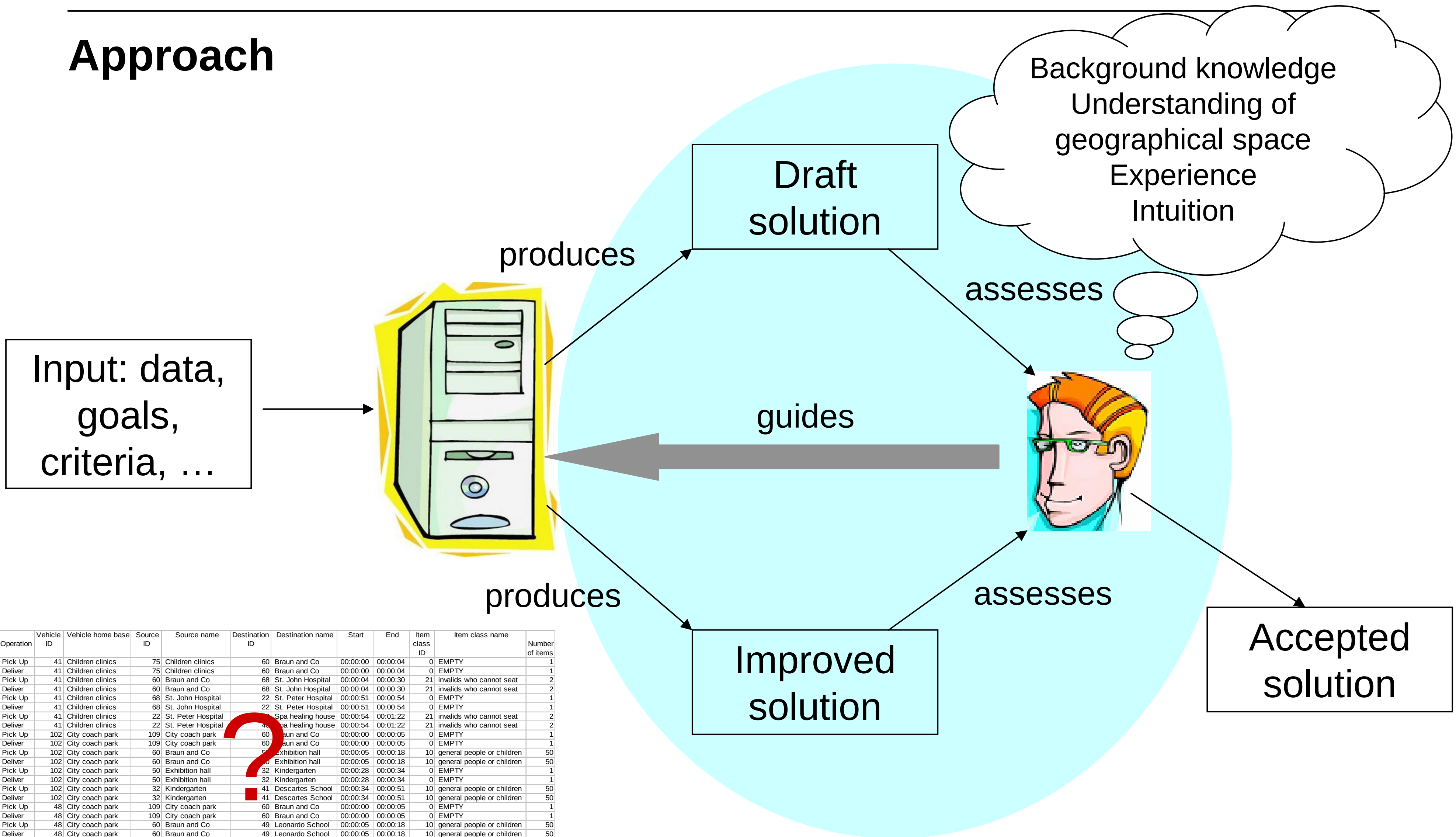


More complex decision problems

- It is not always possible to evaluate decision options in terms of numeric criteria.
- In particular, there is no adequate numeric representation for spatial aspects.
- In many cases, tacit knowledge and criteria play a decisive role.
- A human analyst should be able to see and assess candidate solutions on the basis of his/her knowledge and experience, sense of space, and even common sense.


Time-critical decision problems
Problems involving geographical space and time
Require high efficiency
Involve much data
Complex
Ill-defined
Depend on tacit knowledge and criteria
No adequate computer representation for geographic space
Synergy required!
Background knowledge
Understanding of geographical space
Experience
Intuition
Computational methods
Human expert

Approach



Vehicle class	Operation	Vehicle ID	Vehicle home base	Source ID	Source name	Destination ID	Destination name	Start	End	Item class ID	Item class name	Number of items
20	Pick Up	41	Children clinics	75	Children clinics	60	Braun and Co	00:00:00	00:00:04	0	EMPTY	1
20	Deliver	41	Children clinics	75	Children clinics	60	Braun and Co	00:00:00	00:00:04	0	EMPTY	1
20	Pick Up	41	Children clinics	60	Braun and Co	68	St. John Hospital	00:00:04	00:00:30	21	invalids who cannot seat	2
20	Deliver	41	Children clinics	60	Braun and Co	68	St. John Hospital	00:00:04	00:00:30	21	invalids who cannot seat	2
20	Pick Up	41	Children clinics	68	St. John Hospital	22	St. Peter Hospital	00:00:51	00:00:54	0	EMPTY	1
20	Deliver	41	Children clinics	68	St. John Hospital	22	St. Peter Hospital	00:00:51	00:00:54	0	EMPTY	1
20	Pick Up	41	Children clinics	22	St. Peter Hospital	[illegible]	Spa healing house	00:00:54	00:01:22	21	invalids who cannot seat	2
20	Deliver	41	Children clinics	22	St. Peter Hospital	40	[illegible]pa healing house	00:00:54	00:01:22	21	invalids who cannot seat	2
10	Pick Up	102	City coach park	109	City coach park	60	[illegible]aun and Co	00:00:00	00:00:05	0	EMPTY	1
10	Deliver	102	City coach park	109	City coach park	60	[illegible]aun and Co	00:00:00	00:00:05	0	EMPTY	1
10	Pick Up	102	City coach park	60	Braun and Co	[illegible]	[illegible]xhibition hall	00:00:05	00:00:18	10	general people or children	50
10	Deliver	102	City coach park	60	Braun and Co	[illegible]	Exhibition hall	00:00:05	00:00:18	10	general people or children	50
10	Pick Up	102	City coach park	50	Exhibition hall	32	Kindergarten	00:00:28	00:00:34	0	EMPTY	1
10	Deliver	102	City coach park	50	Exhibition hall	32	Kindergarten	00:00:28	00:00:34	0	EMPTY	1
10	Pick Up	102	City coach park	32	Kindergarten	41	Descartes School	00:00:34	00:00:51	10	general people or children	50
10	Deliver	102	City coach park	32	Kindergarten	41	Descartes School	00:00:34	00:00:51	10	general people or children	50
10	Pick Up	48	City coach park	109	City coach park	60	Braun and Co	00:00:00	00:00:05	0	EMPTY	1
10	Deliver	48	City coach park	109	City coach park	60	Braun and Co	00:00:00	00:00:05	0	EMPTY	1
10	Pick Up	48	City coach park	60	Braun and Co	49	Leonardo School	00:00:05	00:00:18	10	general people or children	50
10	Deliver	48	City coach park	60	Braun and Co	49	Leonardo School	00:00:05	00:00:18	10	general people or children	50
10	Pick Up	48	City coach park	49	Leonardo School	5	Frings Gymnasium	00:00:28	00:00:33	0	EMPTY	1
10	Deliver	48	City coach park	49	Leonardo School	5	Frings Gymnasium	00:00:28	00:00:33	0	EMPTY	1
10	Pick Up	48	City coach park	5	Frings Gymnasium	41	Descartes School	00:00:33	00:00:48	10	general people or children	50
10	Deliver	48	City coach park	5	Frings Gymnasium	41	Descartes School	00:00:33	00:00:48	10	general people or children	50
10	Pick Up	78	City coach park	109	City coach park	21	Kindergarten	00:00:00	00:00:05	0	EMPTY	1
10	Deliver	78	City coach park	109	City coach park	21	Kindergarten	00:00:00	00:00:05	0	EMPTY	1
10	Pick Up	78	City coach park	21	Kindergarten	50	Exhibition hall	00:00:05	00:00:19	10	general people or children	20
10	Deliver	78	City coach park	21	Kindergarten	50	Exhibition hall	00:00:05	00:00:19	10	general people or children	20
10	Pick Up	78	City coach park	50	Exhibition hall	18	Albert College	00:00:29	00:00:35	0	EMPTY	1
10	Deliver	78	City coach park	50	Exhibition hall	18	Albert College	00:00:29	00:00:35	0	EMPTY	1
10	Pick Up	78	City coach park	18	Albert College	42	Riverside hall	00:00:35	00:00:52	10	general people or children	50
10	Deliver	78	City coach park	18	Albert College	42	Riverside hall	00:00:35	00:00:52	10	general people or children	50
12	Pick Up	117	Bus travel company	110	Bus travel company	60	Braun and Co	00:00:00	00:00:06	0	EMPTY	1
12	Deliver	117	Bus travel company	110	Bus travel company	60	Braun and Co	00:00:00	00:00:06	0	EMPTY	1
12	Pick Up	117	Bus travel company	60	Braun and Co	42	Riverside hall	00:00:06	00:00:23	10	general people or children	100
12	Deliver	117	Bus travel company	60	Braun and Co	42	Riverside hall	00:00:06	00:00:23	10	general people or children	100

?

Requires visualisation!

Example: emergency evacuation problem

- Several categories of people
  - General public; critically sick or injured people; disabled people who can/cannot sit, prisoners, …
- Multiple source locations
  - Number of people of different categories
  - Time constraints (e.g. latest allowed departure time)
- Multiple destinations
  - Suitability and capacity for different categories
- Different types of vehicles
  - E.g. buses, ambulance cars, police vans, …
  - Suitability and capacity for different people categories
- Task:
  - divide people into groups fitting in available types of vehicles
  - assign the groups to suitable destinations
  - find appropriate vehicles to deliver them
  - set the times for the trips of the vehicles

Scheduling Algorithm

- For transportation problems, heuristic methods work better than deterministic approaches
- We apply Breeder Genetic Algorithm (devised by Bartling & Muehlenbein)
- Extended functionality as compared to typical tools for business applications:
  - Divides the total number of people in a location into groups fitting in available vehicles
  - Chooses an appropriate destination for each group
- “Any-time” method:
  - valid solution exists at any moment
  - while the quality is progressively improved as the algorithm continues its work

Generally, the design of candidate solutions is done in a domain- and problem-specific way

Algorithm output

e.g.
- 14 source locations
- 4692 people
- 6 categories
- 105 vehicles
- 7 vehicle types
- 25 destinations

~ 400 transportation orders

OrderId	SourceName	DestName	ItemClass	Number	VhclId	VhclType	VhclHBName	StartTime	EndTime
12-4	St. John Hospital	St. Peter Hospital	LEER	0	12	20	University clinics	00:32:40	00:40:40
72-1	Braun and Co	Exhibition hall	general people or children	50	72	10	City coach park	00:11:00	00:20:40
61-4	Albert College	Descartes School	general people or children	40	61	10	City coach park	00:31:00	00:50:20
29-1	Braun and Co	Rehabilitation Centre	critically sick or injured people	1	29	21	Children Clinics	00:05:00	00:11:20
63-0	City coach park	ABC mall	LEER	0	63	10	City coach park	00:00:00	00:11:00
43-6	Beethoven Gymnasiu	Galileo College	general people or children	50	43	10	City coach park	00:48:20	01:11:00
53-0	City coach park	ABC mall	LEER	0	53	10	City coach park	00:00:00	00:11:00
12-1	St. Peter Hospital	University clinics	invalids who cannot seat	2	12	20	University clinics	00:08:00	00:16:10
56-3	Kindergarten	Plato Gympasium	general people or children	50	56	10	City coach park	00:33:20	00:50:00
58-4	Albert College	City hall	general people or children	20	58	10	City coach park	00:37:00	00:43:40
46-0	City coach park	Real school	LEER	0	46	10	City coach park	00:00:00	00:13:00
43-1	ABC mall	Leonardo School	general people or children	20	43	10	City coach park	00:12:00	00:21:40
58-5	City hall	Albert College	LEER	0	58	10	City coach park	00:44:40	00:50:40
91-2	Elder home	Children Clinics	sabled people using wheelchairs	8	91	13	Bus travel compan	00:27:40	00:36:00
86-0	Bus travel company A	Albert College	LEER	0	86	10	Bus travel compan	00:00:00	00:11:00
61-1	Braun and Co	City hall	general people or children	40	61	10	City coach park	00:11:00	00:23:40
23-0	Children Clinics	Braun and Co	LEER	0	23	20	Children Clinics	00:00:00	00:05:00
47-1	Braun and Co	Helmholtz Gymnasium	general people or children	50	47	10	City coach park	00:11:00	00:24:40
40-5	Beethoven Gymnasiu	St. Teresa's school	general people or children	20	40	10	City coach park	00:28:40	00:44:40
52-4	St.Joseph's basic sch	Helmholtz Gymnasium	general people or children	50	52	10	City coach park	00:34:20	00:44:00
20-3	Elder home	Children clinics	invalids who cannot seat	2	20	20	St. John Hospital	00:26:20	00:33:30
103-0	Jailhouse	Prison	LEER	0	103	30	Jailhouse	00:00:00	00:46:00
11-0	St. Peter Hospital	Braun and Co	LEER	0	11	21	St. Peter Hospital	00:00:00	00:08:00
17-1	Braun and Co	Children clinics	critically sick or injured people	1	17	21	University clinics	00:16:00	00:22:20
6-2	Braun and Co	Children clinics	invalids who cannot seat	2	6	20	St. Peter Hospital	00:17:20	00:23:30
58-3	Exhibition hall	Albert College	LEER	0	58	10	City coach park	00:22:00	00:37:00
54-2	City hall	Albert College	LEER	0	54	10	City coach park	00:25:20	00:31:20
52-2	Braun and Co	City hall	general people or children	40	52	10	City coach park	00:13:20	00:25:40
44-0	City coach park	Braun and Co	LEER	0	44	10	City coach park	00:00:00	00:11:00
52-5	Helmholtz Gymnasiur	St.Joseph's basic schc	LEER	0	52	10	City coach park	00:45:40	00:53:40
61-3	City hall	Albert College	LEER	0	61	10	City coach park	00:25:00	00:31:00
25-6	University clinics	St. Peter Hospital	LEER	0	25	20	Children Clinics	00:47:00	00:55:00
61-0	City coach park	Braun and Co	LEER	0	61	10	City coach park	00:00:00	00:11:00
81-5	Albert College	Heighbourhood House	general people or children	40	81	10	City coach park	00:56:00	01:08:20

No time to inspect all the orders!

Cannot be summarized in a few indicators!

Schedule evaluation

- Questions to be answered:
- Does the plan achieve the goal?
  - Goal: all people are timely delivered to appropriate destination places by appropriate vehicles
- Is it feasible?
- Is it rational?

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Possible problems

Undelivered people	Can emerge due to lack or deficiency of resources Require human to find appropriate corrective measures (additional vehicles, additional or intermediate destinations, …)
Late deliveries w.r.t. time constraints	
Use of improper vehicles	
Delivery to improper places	
Overuse of resources	Excluded by the algorithm, but correctness should be demonstrated
Multiple vehicles in same place	May be a problem or an advantage; requires human's local knowledge
Idle vehicles	Lower priority; may be examined when time permits
Choice of distant destinations	
Low use of vehicle capacities	

Effectiveness problems (i.e. goal not attained)

Feasibility problems

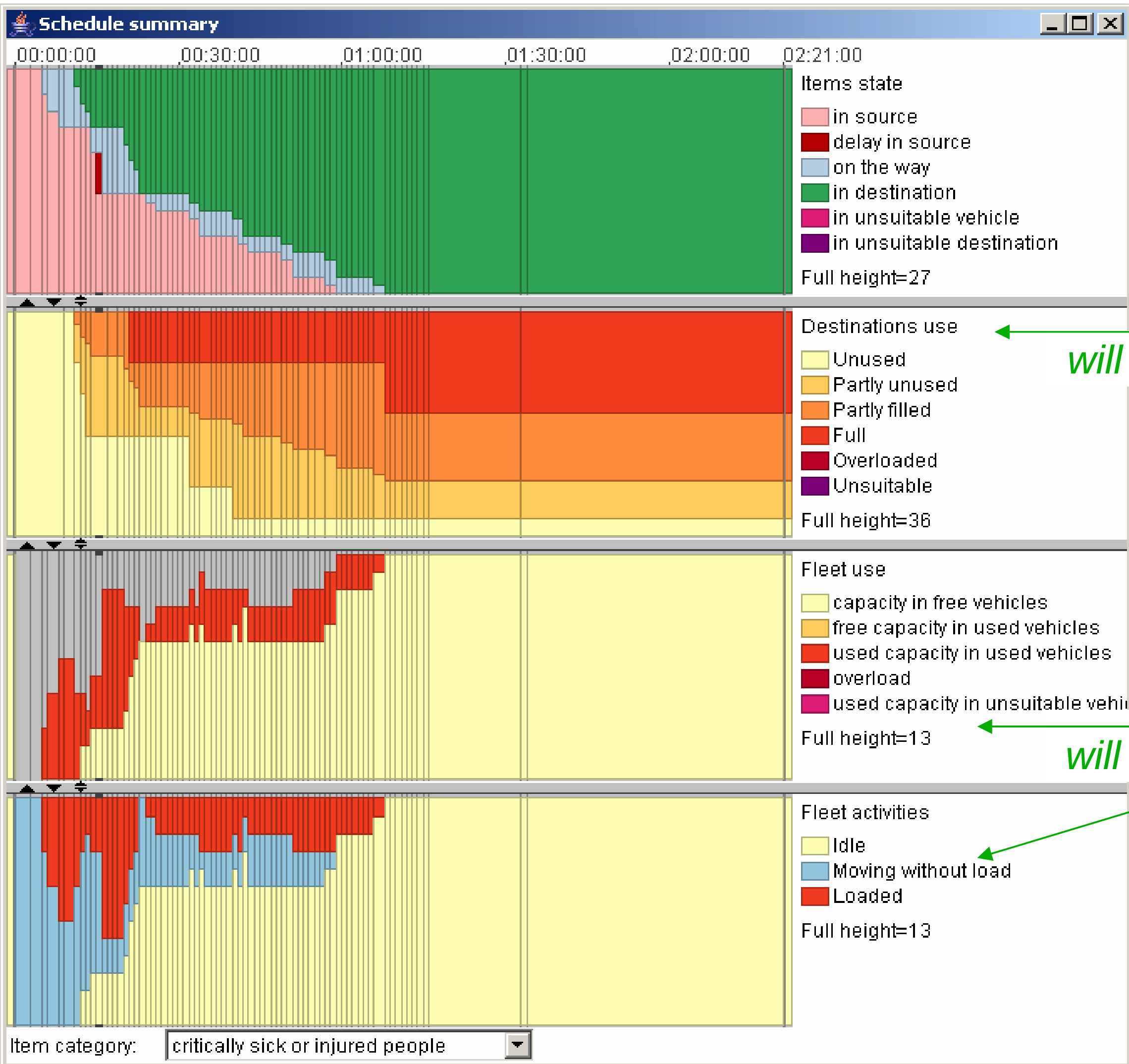
Rationality problems

Requirements

- The presence or absence of effectiveness and feasibility problems must be immediately visible
- In case of problems, the reasons must be immediately seen or easy to find out
  - Undelivered people, use of improper destinations ⇐ lack of suitable destinations
  - Late deliveries, use of improper vehicles ⇐ deficiency of suitable vehicles
  - Multiple vehicles in same place: examine each place individually
- It must be possible to spot and explore rationality problems when time permits

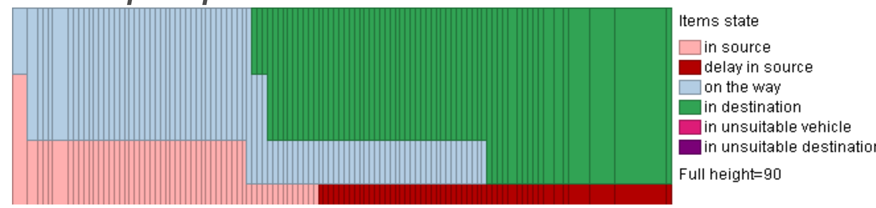
Show the Most Important

Summary display of the transportation progress:



Signals of problems:

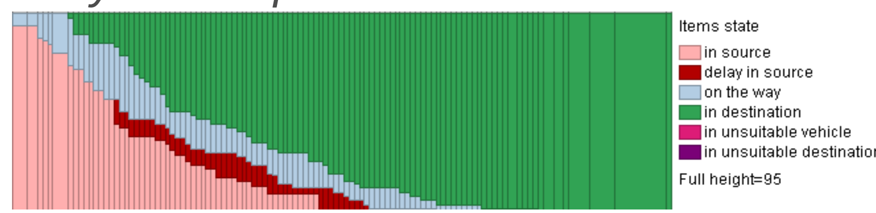
Some people are not delivered



Reason: lack of destinations

will be seen here

Delay in transportation

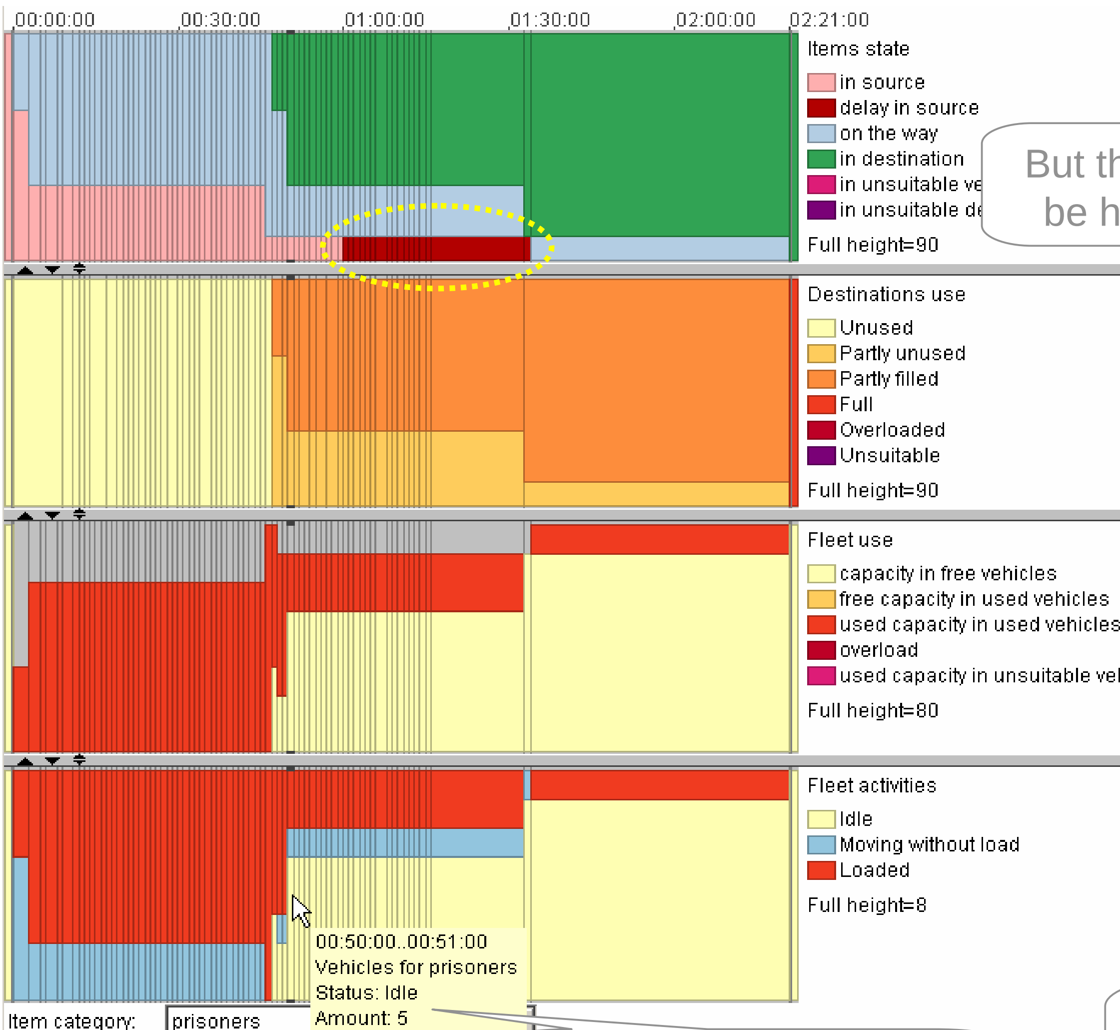


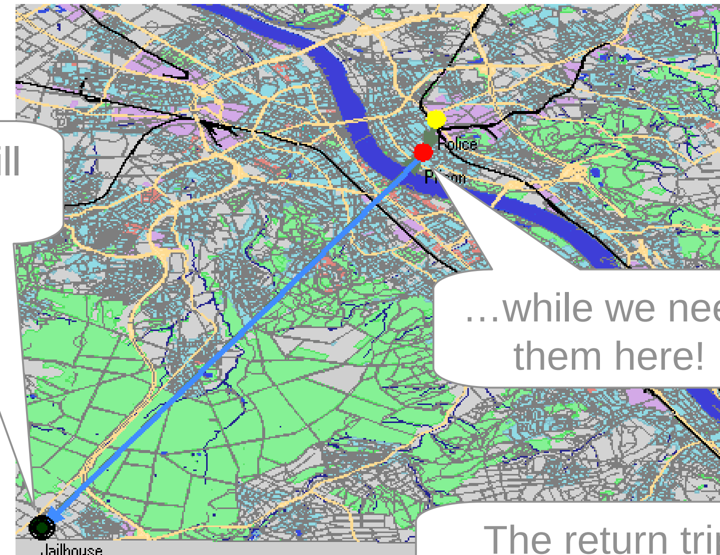
Reason: not enough vehicles

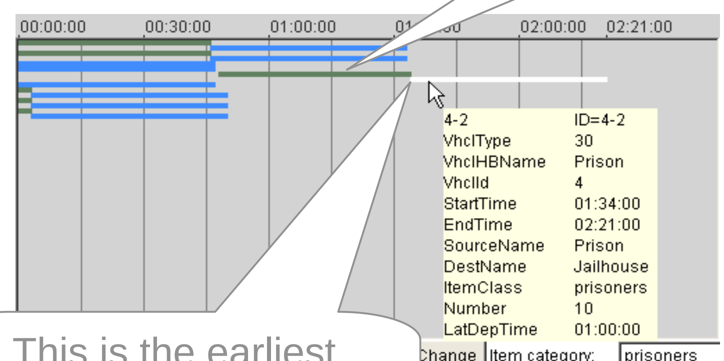
will be seen here

Not always the reason is evident…

Find a non-evident reason for a delay







But they will be here…

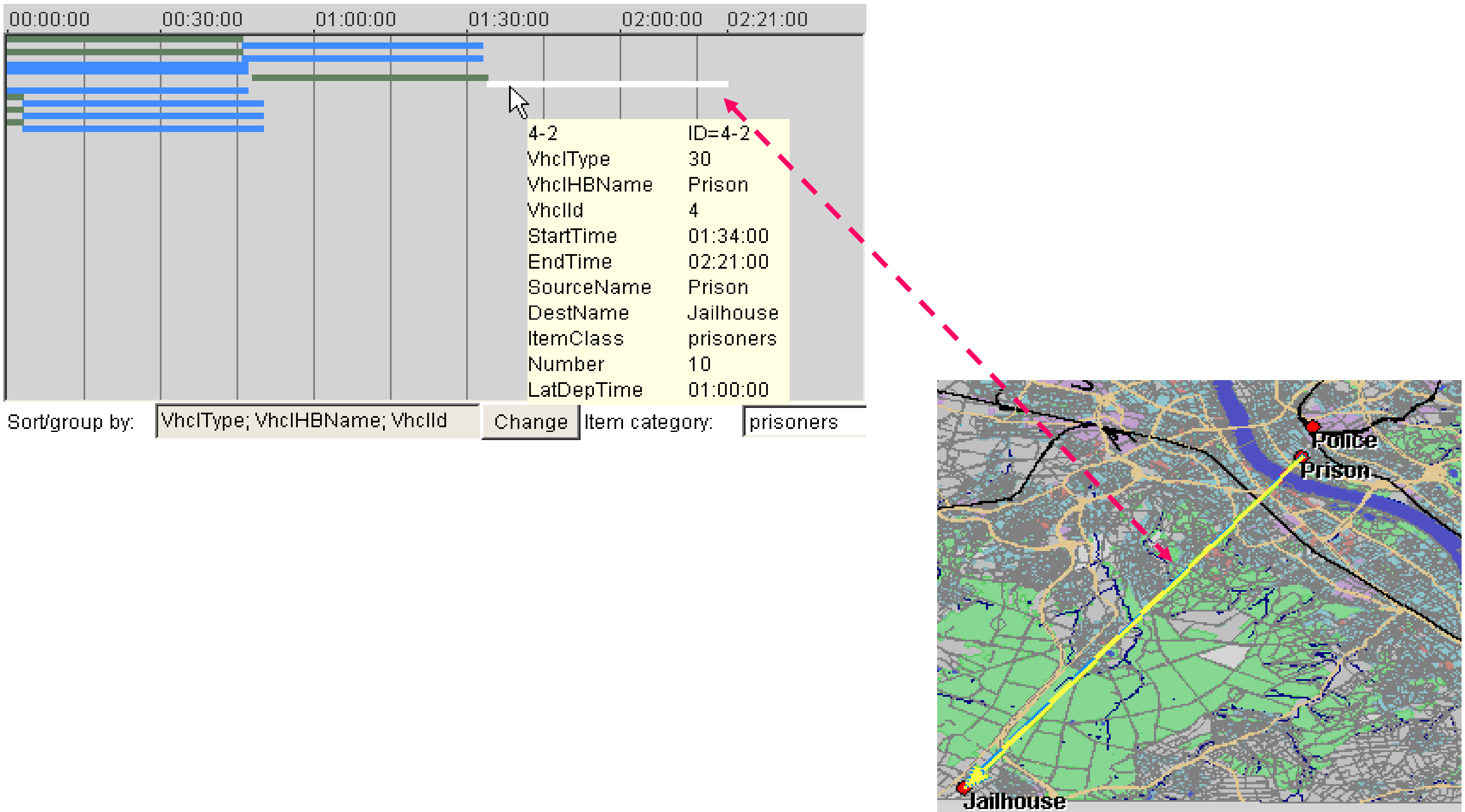
…while we need them here!

The return trip takes 47 minutes

This is the earliest possible time for taking the remaining prisoners

At this time we shall have 5 free vehicles!

Details on demand



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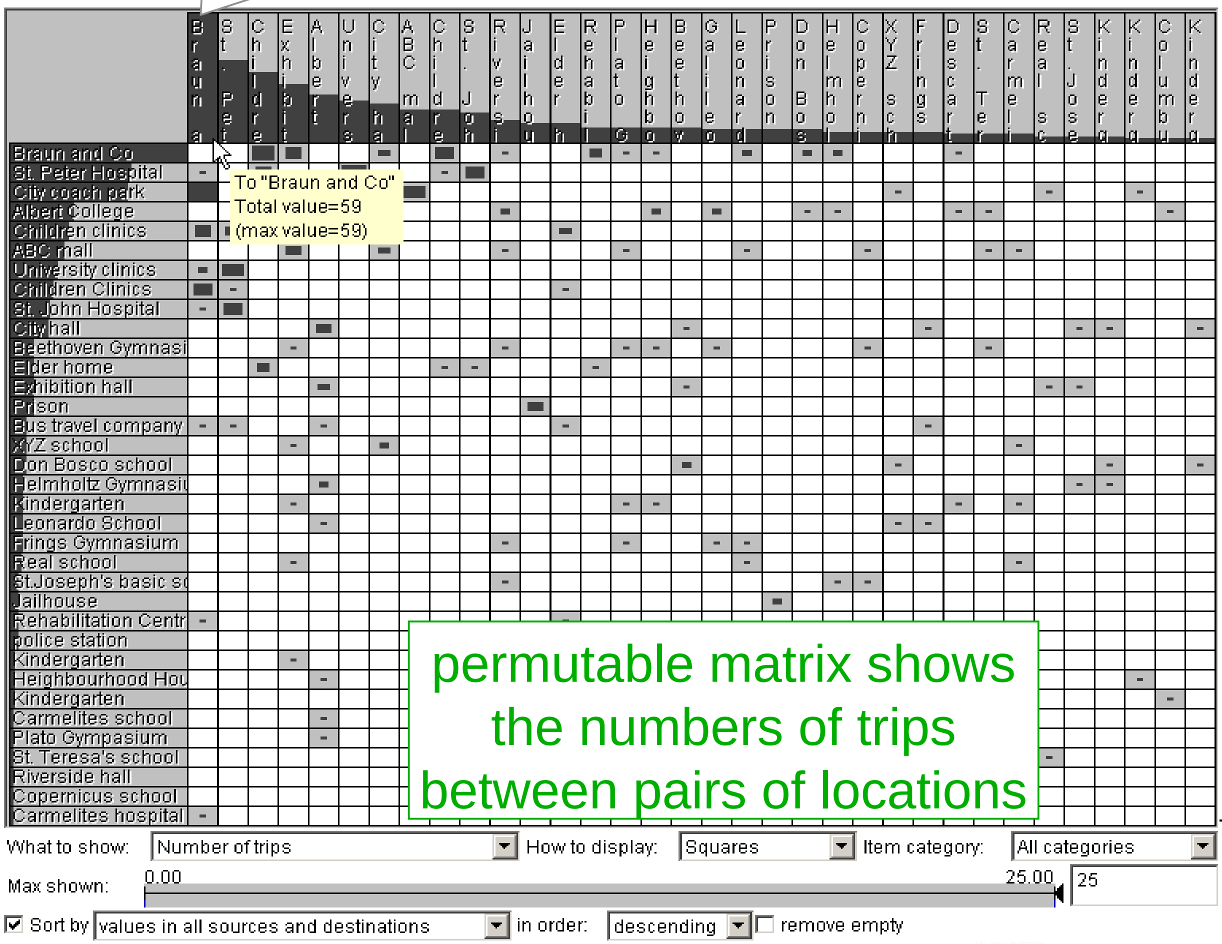
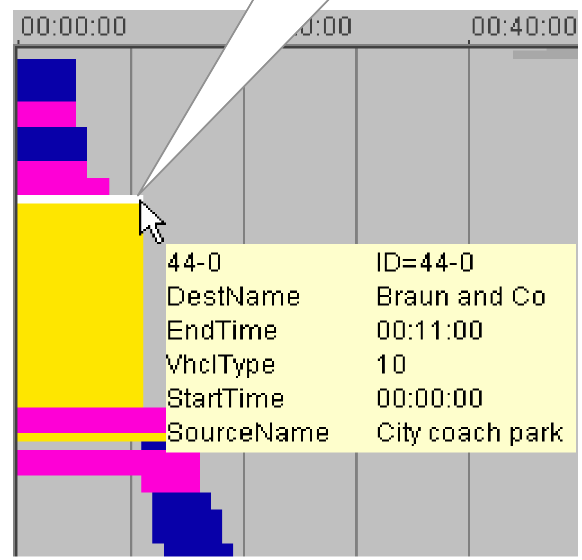
Check the feasibility

So many trips to ‘Braun and Co’!
How are they distributed in time?



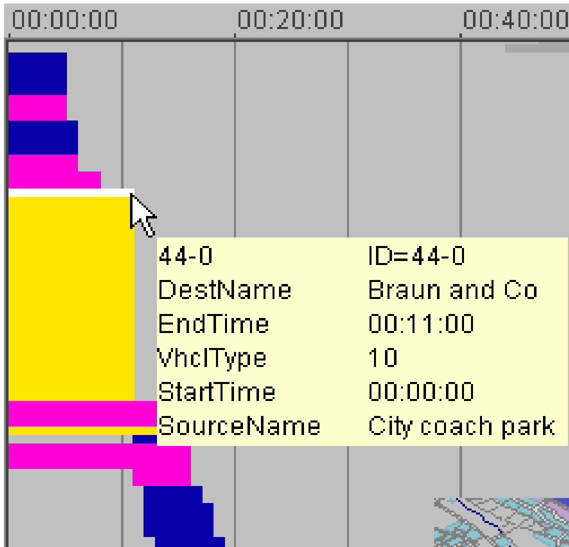
permutable matrix shows the numbers of trips between pairs of locations

23 buses come simultaneously!

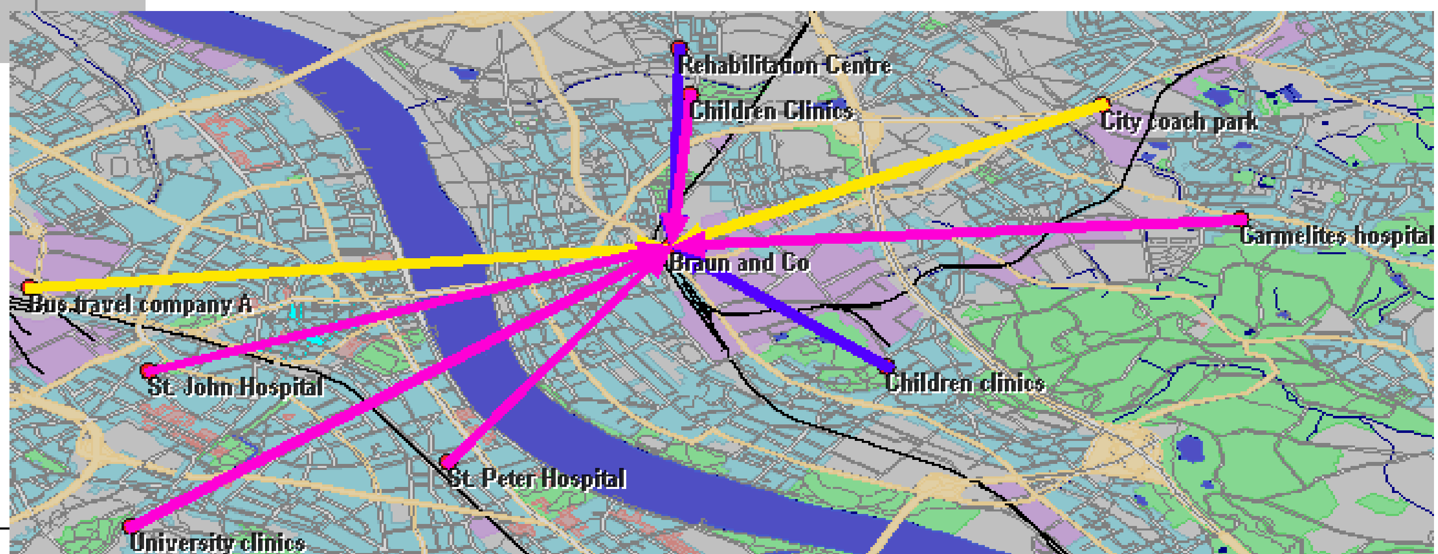


…but this is a big chemical plant with a large parking

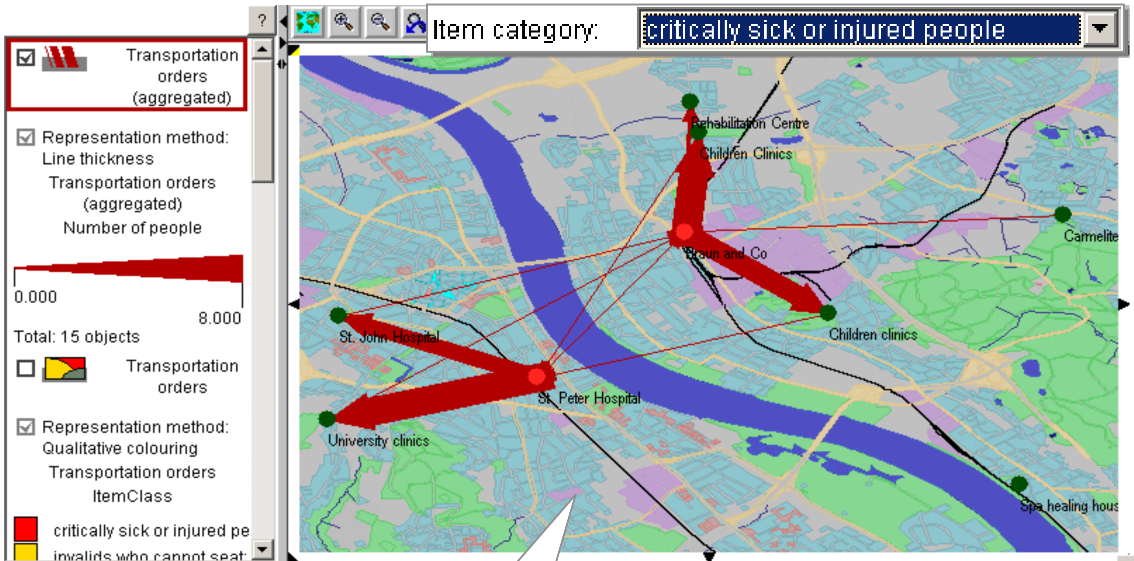
Details on demand



We see from what places vehicles will come to take people from Braun and Co

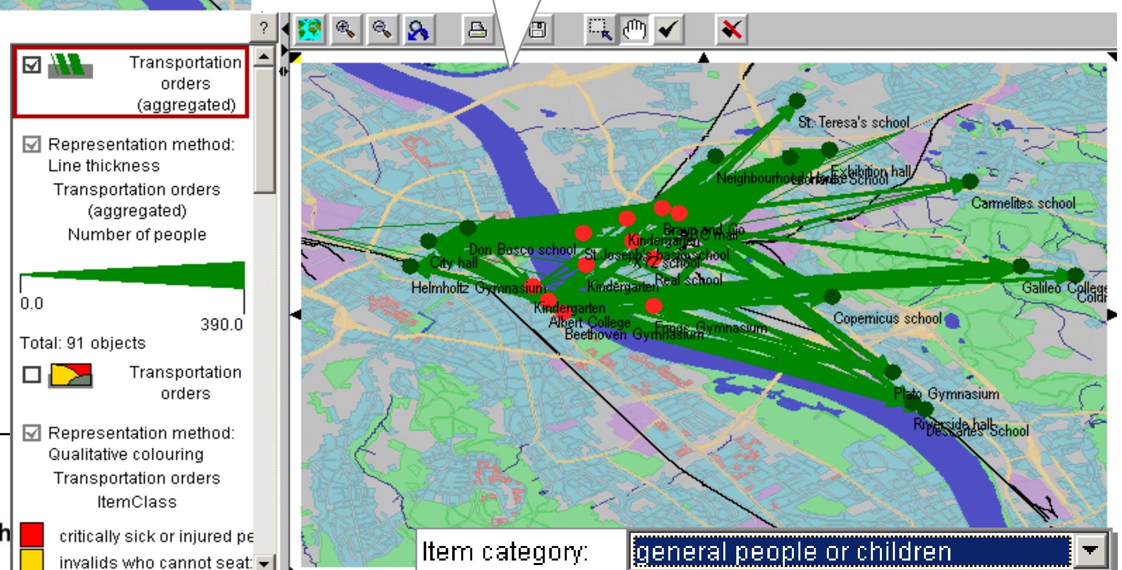


Assess the rationality

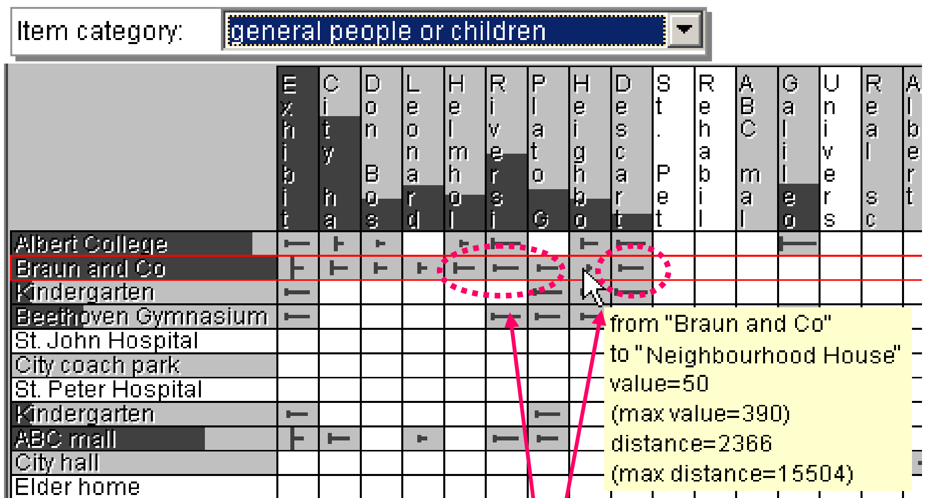


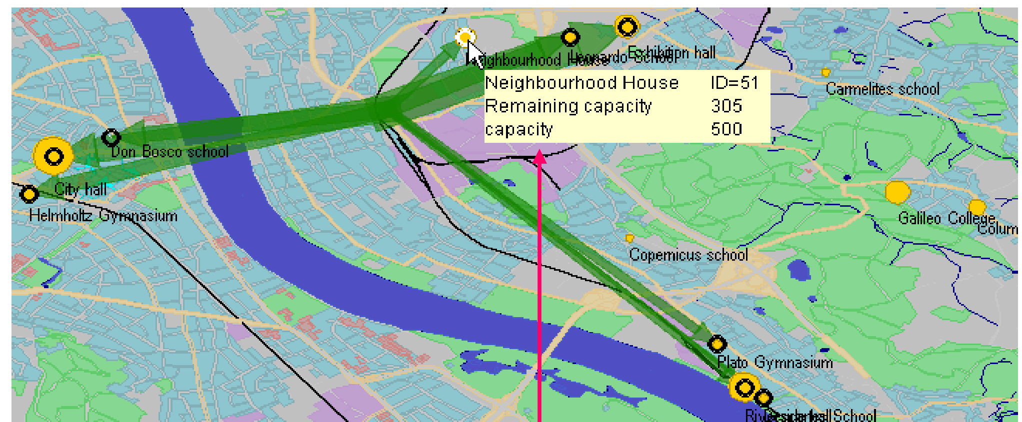
The choice of the destinations for the critically sick and injured persons seems quite reasonable

But it is hard to see anything when we focus on the general people…



Assess the rationality (continued)



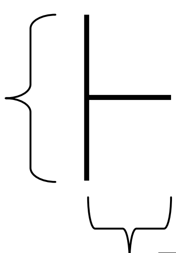


Some people will be moved quite far…

… while the capacities in the closer destinations are not fully used

T-shaped signs:

Number of items



Travel time

The planner may wish to change this…

if the time permits!

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Reasons for Schedule Modification

- Undelivered people
  - Requires finding additional destinations
- Unacceptable delays
  - Requires finding additional vehicles or closer destinations (possibly, intermediate)
- Multiple vehicles in same place
  - The planner may shift some orders forward in time
- Non-rational choice of destinations and use of capacities in destinations
  - The planner may exclude distant places
- Situation changes after the evacuation started
  - New people appear, some destinations become unavailable (e.g. roads blocked), some vehicles get out of use, trips take longer than expected, …

General Procedure

- Divide the orders into fixed and modifiable
  - by people category (e.g. ‘critically sick’ → fixed, ‘prisoners’ → modifiable)
  - by time: fix all trips starting before t
    - in particular, for adapting to the changing situation
  - by source location (e.g. from ‘Braun and Co’ → modifiable)
  - by a combination of these criteria
- Update the input data
  - Add data about new sources, people, resources
  - Remove unavailable resources
  - Correct the travel times
- Re-run the scheduling algorithm (it is appropriately designed)

Summary

- Decision support includes various technologies supporting different stages of human decision making process: intelligence, design, and choice
- The need for visual analytics methods on the stage of intelligence is the most evident
- We have considered the possible computational and visual support to the stage of choice: multi-criteria evaluation and ranking in case of numeric criteria
- However, real-world problems may be complex, possible solutions not quantifiable
- Human assessment of possible solutions is essential
- Solutions may be very complex constructs involving spatial and temporal components
- Visual analytics techniques are needed to support the assessment of such constructs by a human analyst or decision maker

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See also

- <u>Spatial decision support, role of visual analytics:</u>

  Gennady Andrienko, Natalia Andrienko, Piotr Jankowski, Menno-Jan Kraak, Daniel Keim, Alan MacEachren, Stefan Wrobel
  Geovisual Analytics for Spatial Decision Support. Setting the Research Agenda
  International Journal of Geographical Information Science,
  2007, v.**21** (8), pp. 839-857

- <u>Multicriteria optimization:</u>

  Andrienko, N., Andrienko, G.
  Informed Spatial Decisions through Coordinated Views
  Information Visualization
  2003, v.**2** (4), pp. 270-285.

- <u>Evacuation scheduling:</u>

  Gennady Andrienko, Natalia Andrienko, Ulrich Bartling
  Visual Analytics Approach to User-Controlled Evacuation Scheduling
  Information Visualization,
  2008, v.**7** (1), pp. 89-103

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