Decision Support

2st INFRALERT Open Workshop 17.04.2018

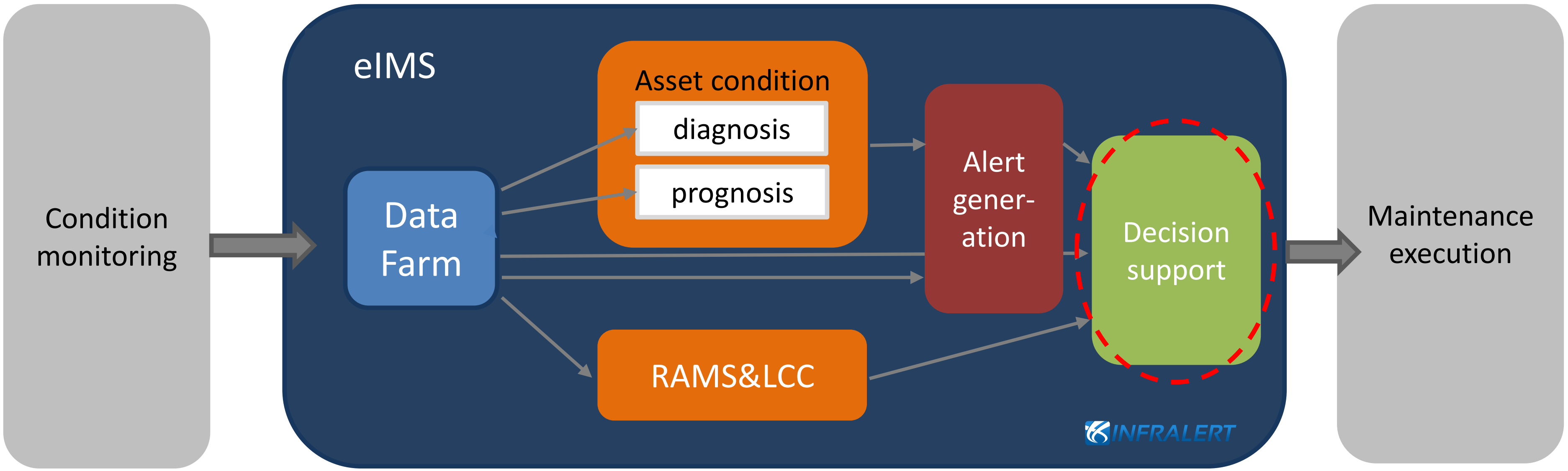
Ute Kandler

Fraunhofer IVI

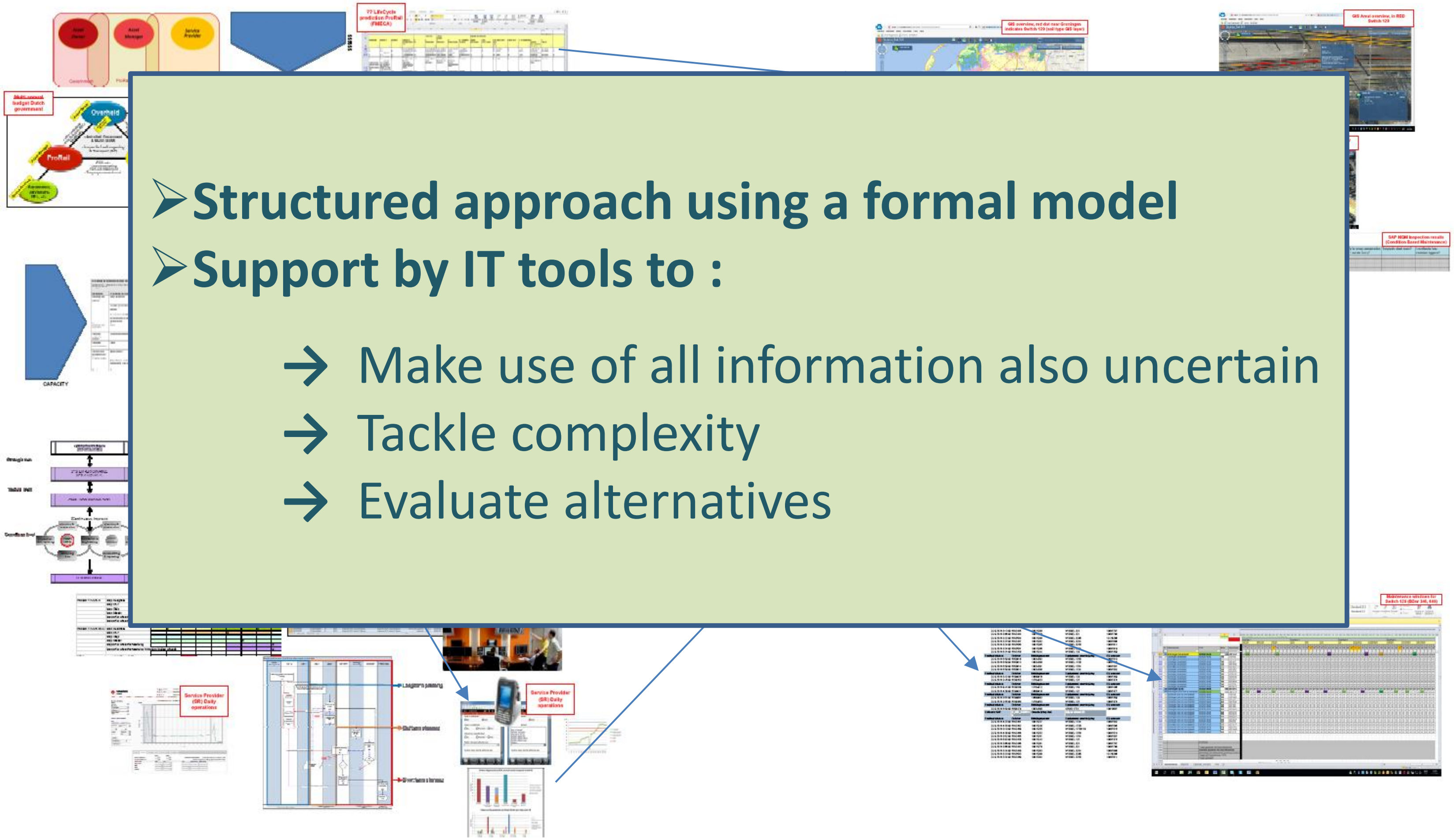
Agenda

- Introduction
  - Decision support embedded in the eIMS
  - Planning problem
  - Monte Carlo Rollout
- Road use case
  - Description of the use case
  - Methodology
  - Results
- Rail use case
  - Description of the use case
  - Methodology
  - Results
- Outlook and Conclusions

General Overview



Introduction



➢ **Structured approach using a formal model**

➢ **Support by IT tools to :**

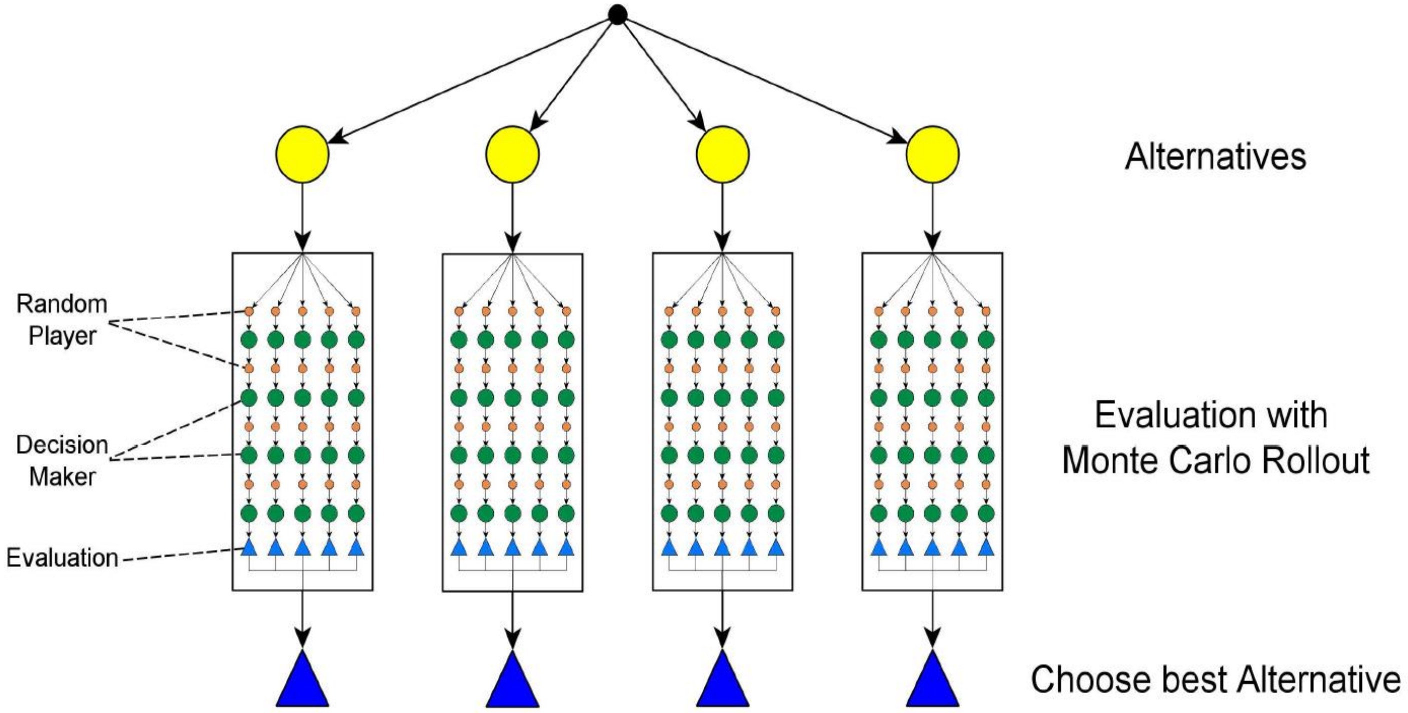
→ Make use of all information also uncertain

→ Tackle complexity

→ Evaluate alternatives

Monte Carlo Rollout

INFRALERT



<u>Main idea</u>:

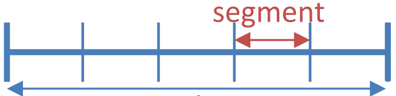
- create a set of different desicions (called alternatives)
- evaluate each alternative using a set of future scenarios
- Based on this evaluation the best alternative is choosen

Description of the Road use case

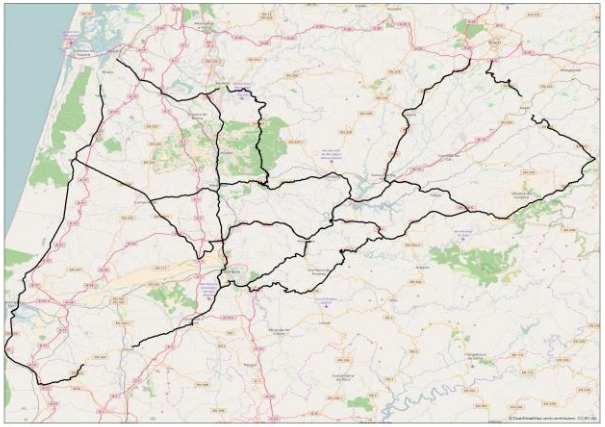
Mid-term road maintenance planning for IP

INFRALERT

- Planning task:
  - Optimal allocation of maintenance interventions on 500m road segments in mid-term (5 years ahead)



- Decisions to make:
  - Selection of “Minimum intervention level”
  - Assignment of “Starting date” (on a monthly basis)
- Objectives/KPIs to be optimized:
  - Minimize costs for maintenance intervention
  - Maximize road quality index
    (which depends on forecasted condition)
  - Maximize availability of the network
    (or conversely minimize the reduction of sections availability due to interventions)



Infraestruturas de Portugal

Description of the Road use case

Mid-term road maintenance planning for IP

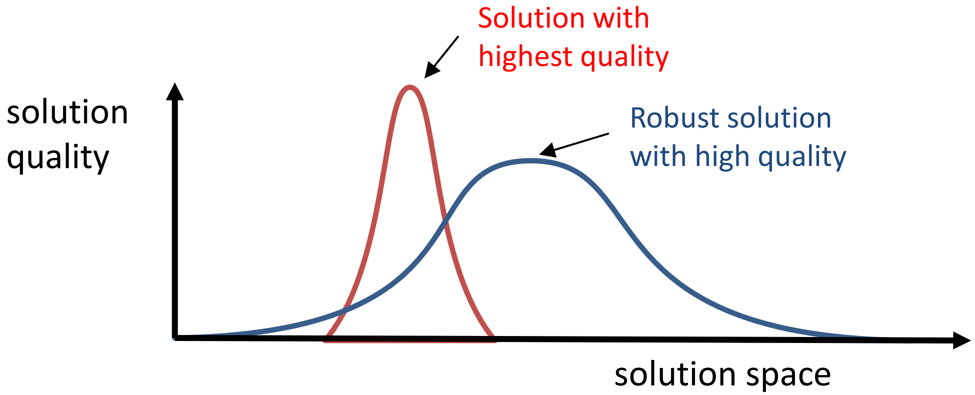
- Constraints:
  - Minimum quality level for the different road segments
  - Maximum overall budget for 5 years
    (also budget restrictions on the yearly basis)
  - Limited capacity of supervisory staff
    (number of interventions allocated to certain region is restricted)
  - each section can be only maintained once during the planning horizon
  - Ensuring certain network avalability

Description of the Road use case

Mid-term road maintenance planning for IP

- The main challenge:
  - Due to uncertain degradation and condition development:
    - allocated interventions are only predicted ("most probable")
  - Unknown during planning, only known at execution time:
    - condition of the asset
    - segments affected
    - associated duration and cost of the intervention

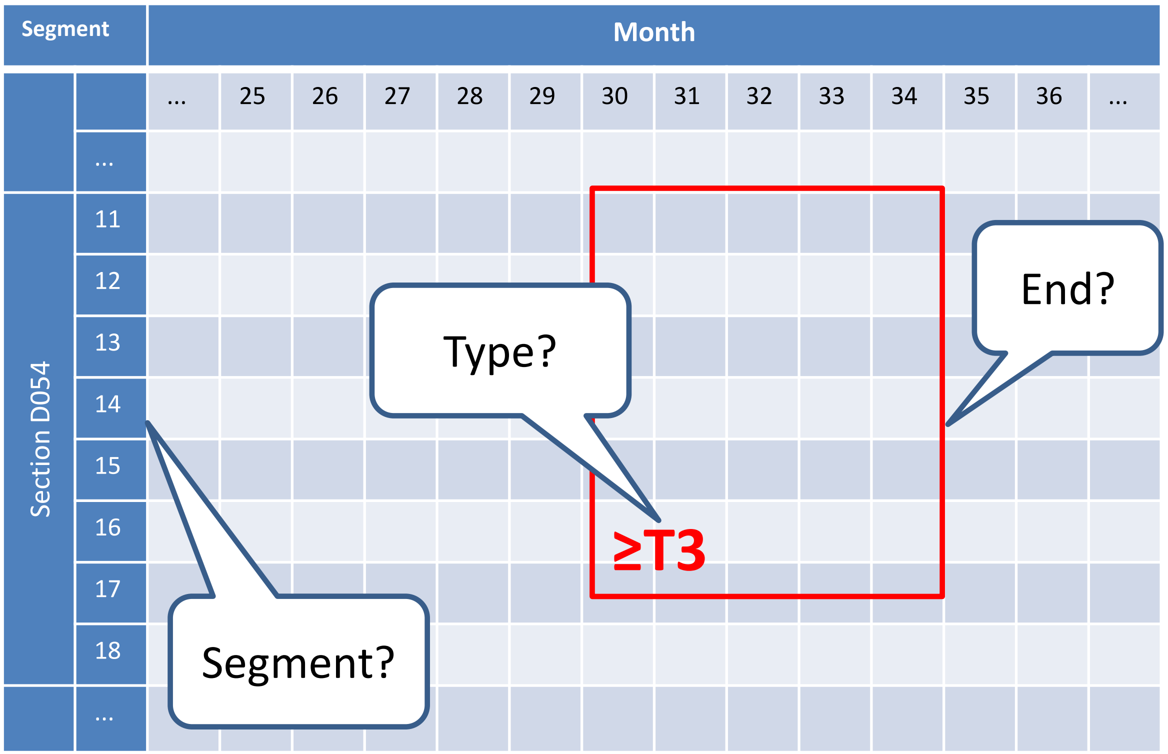
→ planning looks for **ROBUST** solutions!



Road Use Case - Methodology

INFRALERT

How to generate an event intervention?

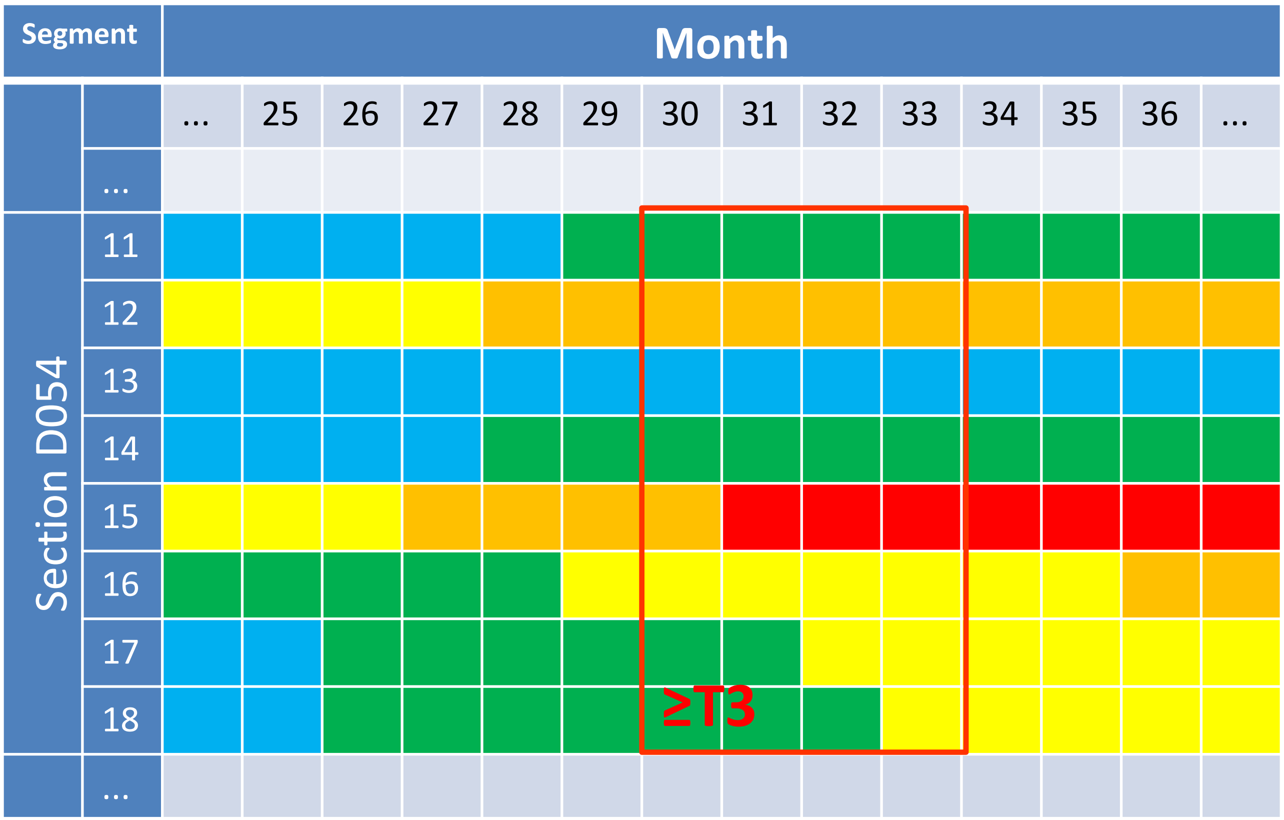


	Alert	Description
T0	No	No maintenance requested
T1	Yes	Do nothing.
T2	Yes	Microsurfacing, Surface dressing
T3	Yes	Thin Hot-Mix Asphalt overlay (≤5cm)
T31	Yes	Surface milling with thin Hot-Mix Asphalt overlay (≥5cm)
T4	Yes	Thin Hot-Mix Asphalt overlay (>5cm) combined with milling

Road Use Case - Methodology

INFRALERT

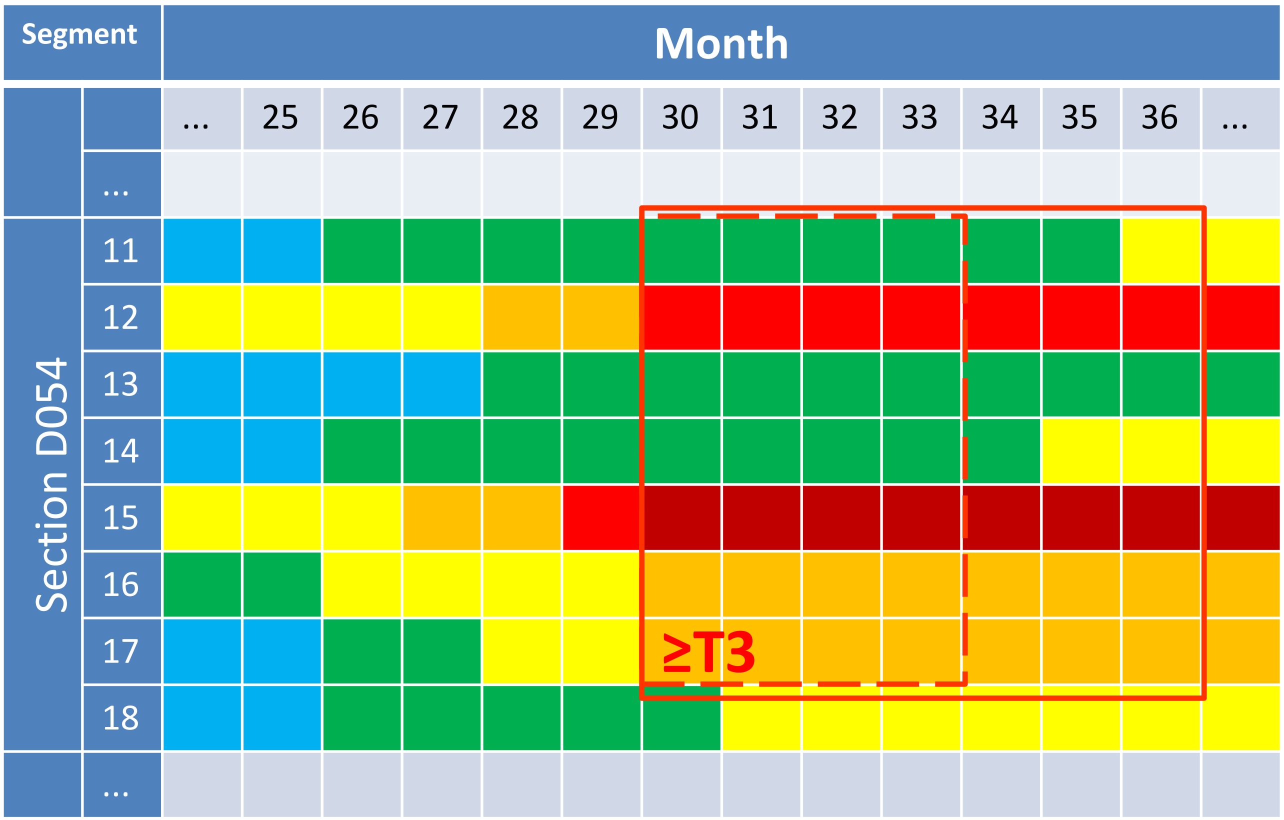
- Plan is „good“ in this scenario



	Alert	Description
T0	No	No maintenance requested
T1	Yes	Do nothing.
T2	Yes	Microsurfacing, Surface dressing
T3	Yes	Thin Hot-Mix Asphalt overlay (≤5cm)
T31	Yes	Surface milling with thin Hot-Mix Asphalt overlay (≥5cm)
T4	Yes	Thin Hot-Mix Asphalt overlay (>5cm) combined with milling

Road Use Case - Methodology

- Plan is „bad“ in this scenario



	Alert	Description
T0	No	No maintenance requested
T1	Yes	Do nothing.
T2	Yes	Microsurfacing, Surface dressing
T3	Yes	Thin Hot-Mix Asphalt overlay (≤5cm)
T31	Yes	Surface milling with thin Hot-Mix Asphalt overlay (≥5cm)
T4	Yes	Thin Hot-Mix Asphalt overlay (>5cm) combined with milling

Road Use Case - Methodology

INFRALERT

- More robust plan

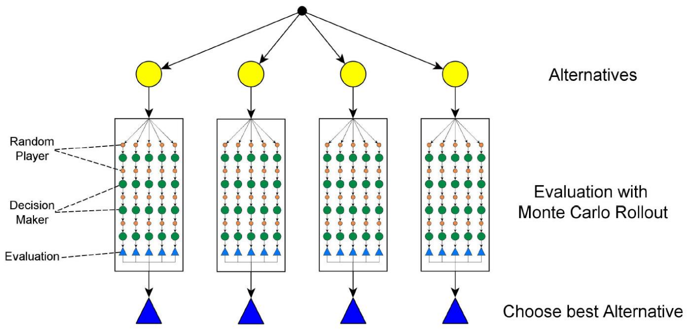
Segment		Month													
		…	25	26	27	28	29	30	31	32	33	34	35	36	…
	…														
Section D054	11														
	12														
	13														
	14														
	15														
	16														
	17														
	18		≥T2												
	…														

	Alert	Description
T0	No	No maintenance requested
T1	Yes	Do nothing.
T2	Yes	Microsurfacing, Surface dressing
T3	Yes	Thin Hot-Mix Asphalt overlay (≤5cm)
T31	Yes	Surface milling with thin Hot-Mix Asphalt overlay (≥5cm)
T4	Yes	Thin Hot-Mix Asphalt overlay (>5cm) combined with milling

Road Use Case - Methodology

INFRALERT

Application of the Monte Carlo Rollout



1. Planning step

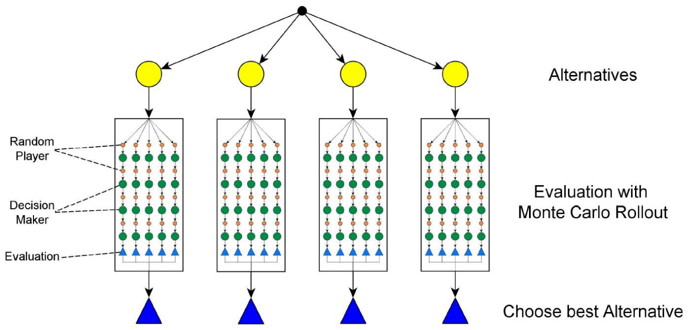
- Rough plan – allocation of interventions into 5 years
- Generate a list with all possible intervention events $e(T_x, t, section)$

  ➡ To specify: intervention level, planning year
- Priorization of all possible intervention events using Δc and Δq
- Selection of n intervention events with highest priority
- Allocation of interventions is modelled via bin packing problem

Road Use Case - Methodology

INFRALERT

Application of the Monte Carlo Rollout



<u>2. Planning Step</u>

- Consider each year separately
- allocation into months
- Priorization using $\Delta c, \Delta q$

➡ Selection of the event with highest priority – allocation into the first month

➡ Select remaining intervention events that „fits best“ (capacity, availability)

  - Capacity constraint satisfied
  - Availability of the network is not allowed to decrease more than $n\%$

Road Use Case – Results

Visualization of the tactical plan

Click to jump to section:

1536	1537	1538	1539	1540	1541	1542	1545	1546	1547	1548	1549	1550	1551	1552	1553	1554	1555	1556	1557
1558	1559	1560	1561	1562	1563	1564	1565	1566	1567	1568	1571	3133	3134	3135	3136	1466	1467	1468	1469
1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489
1490	1491	1492	1495	1496	1497	1498	1499	1501	1502	1503	1504	1505	1506	1507	1508	1510	1511	1513	1515
1516	1519	1520	1522	1523	1524	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534	1535			

Switch | Last section | Next section

Section: 1482 **Quality limit: T31**

Segments:

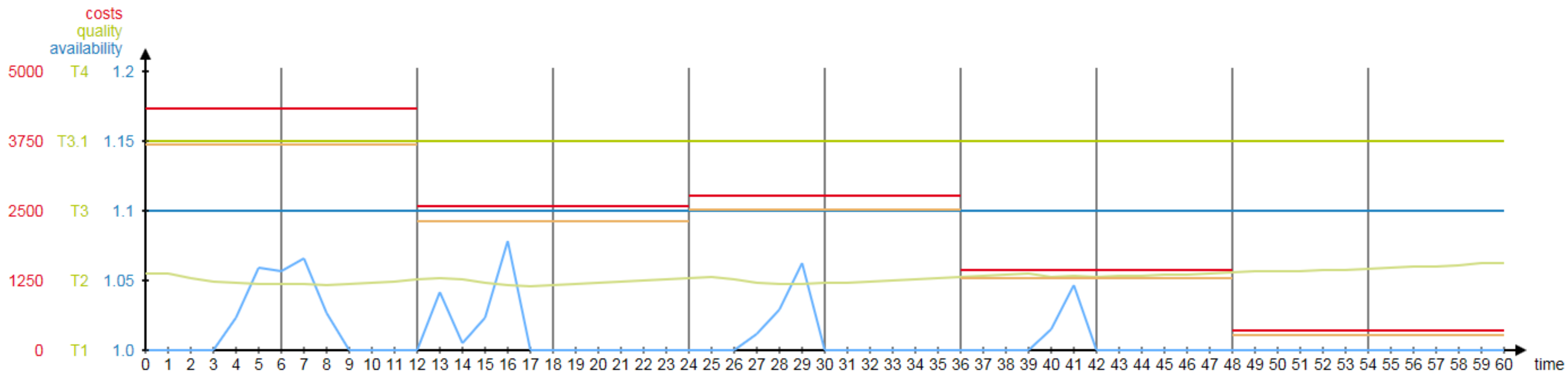
There are events on this section.

m / y	261	262	263	264	265	266	267	268	269	270	271	272	273
1 / 1	T2	T31	T2	T3	T3	T2	T2	T1	T1	T2	T31	T2	T1
2 / 1	T2	T31	T2	T3	T3	T2	T2	T1	T1	T2	T31	T2	[illegible]
3 / 1	T2	T31	T2	T3	T3	T2	T2	T1	T1	T2	T31	T2	[illegible]
4 / 1	T2	T31	T2	T3	T3	T2	T2	T1	T1	T2	T31	T2	[illegible]
5 / 1	T2	T31	T2	T3	T31	T2	T2	T1	T1	T2	T31	T2	[illegible]
6 / 1	T2	T31	T2	T31	T31	T2	T2	T1	T1	T2	T4	T2	[illegible]
7 / 1	T2	T31	T2	T31	T31	T2	T2	T1	T1	T2	T4	T2	[illegible]
8 / 1	T2	T31	T2	T31	T31	T2	T2	T1	T1	T2	T4	T2	[illegible]
9 / 1	T2	T31	T2	T31	T31	T2	T2	T1	T1	T2	T4	T2	T1
10 / 1	T2	T31	T2	T31	T31	T2	T2	T1	T1	T2	T4	T2	T1
11 / 1	T2	T31	T2	T31	T31	T2	T2	T1	T2	T2	T4	T2	T1
12 / 1	T2	T31	T2	T31	T31	T2	T3	T1	T2	T2	T4	T2	T1
1 / 2	T2	T31	T2	T31	T31	T2	T3	T1	T2	T2	T4	T2	T1
2 / 2	T2	T1	T2	T1	T1	T1	T1	T1	T2	T2	T1	T2	T1
3 / 2	T2	T1	T2	T1	T1	T1	T1	T1	T2	T2	T1	T2	T1
4 / 2	T2	T1	T2	T1	T1	T1	T1	T1	T2	T2	T1	T2	T1
5 / 2	T2	T1	T2	T1	T1	T1	T1	T1	T2	T2	T1	T2	T1
6 / 2	T2	T1	T2	T1	T1	T1	T1	T1	T2	T2	T1	T2	T2

EventID: 434
Section: 1482
Quality limit: 2
Costs: 150336
Segments: 262 264 265 266 267 271

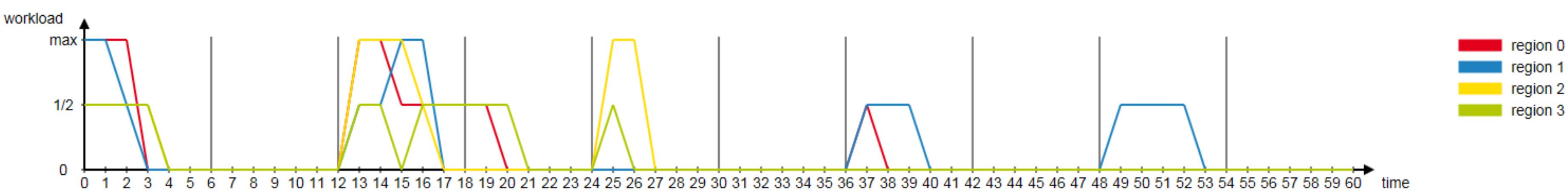
Road Use Case – Results

Validation of the KPIs



Overall costs: 10185591 / 11479514

For each category the lighter color is the value, the darker is the bound.



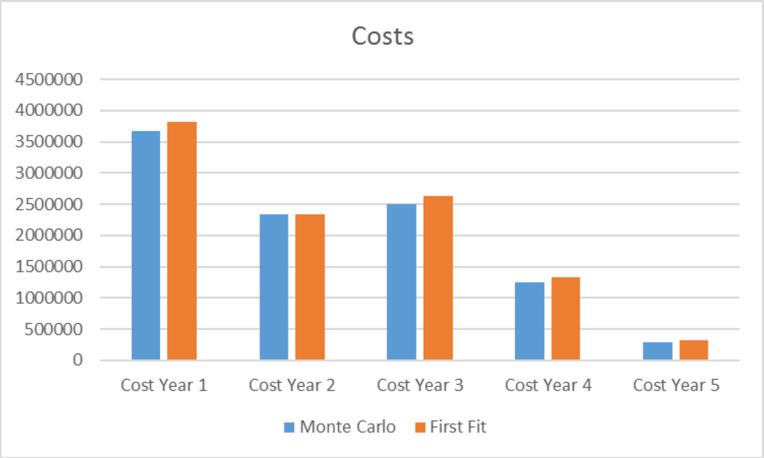
Road Use Case – Results

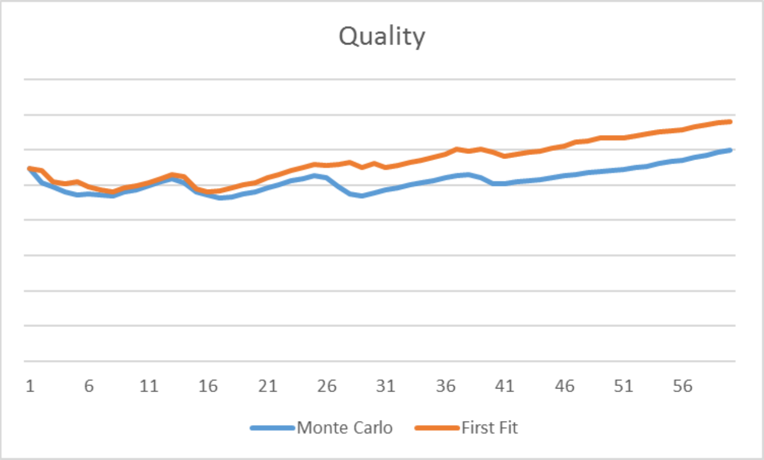
<u>Setting:</u>
- Consider 100 scenarios
- Choose between 20 alternatives in the Monte Carlo Rollout

<u>Evaluation:</u>
- We obtain lower costs and a higher quality
- The more difficult the problem the bigger the advantage

<u>Planned interventions:</u>
Monte Carlo: 71
First Fit: 52

<u>Overall cots:</u>
Monte Carlo: 10047763
First Fit: 10419329





Description of Railway Use case

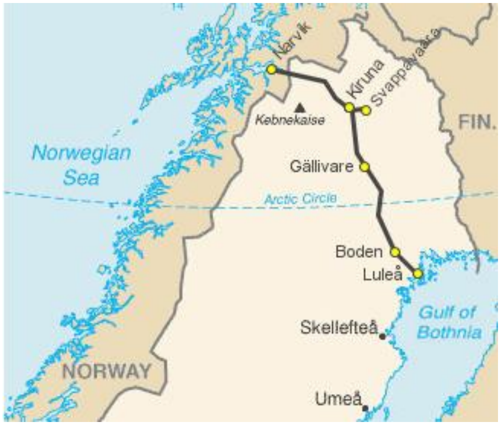
Short-term maintenance planning for TRV

INFRALERT

- Decision to make:
  Allocate maintenance activites to time windows and maintenance crews

- To be optimised:
  Penalty costs for influence in service and for shifting of maintenance activities

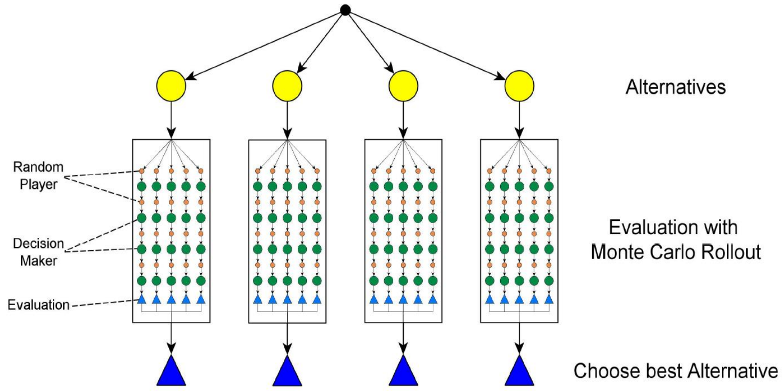
- Constraints:
  - Uncertain duration of maintenance activities
  - Limited budget per week
  - Limited time for maintenance per week
  - Working shift constraints



TRAFIKVERKET

Railway Use case - Methodology

Application of the Monte Carlo Rollout



- Order maintenance activities by priority (sum penalties)
- Alternatives:
  All possible time windows and working teams
- Heuristic: Use best time window
  - Prefer already booked time windows
  - Prefer time slot with most free time
  - Prefer working team with fewest work
- Evaluate Alternatives:
  - Sum of penalties
  - Number of maintenance activities shifted to next week

Railway Use case - Results

Short-term maintenance planning:

time slot
intervention (expected duration)
intervention (90%-quantile)

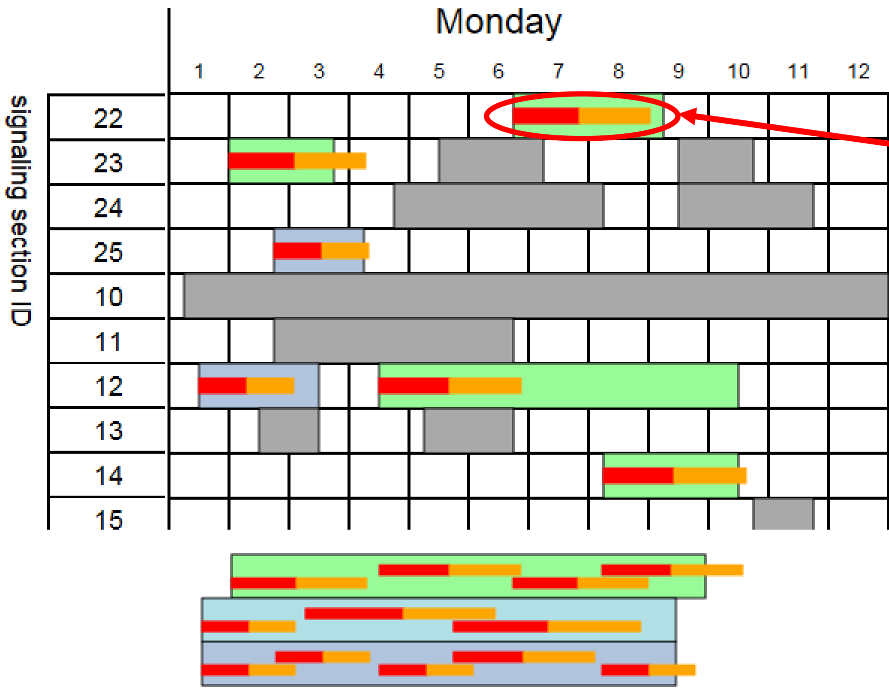
click on object for further information

Back | Forward

penalties: 226326
budget: 64163 / 100000 P=100,0%
availibilty: 3990 / 5303 P=99,6%

planned: 71
shifted: 11

week 51



2018-12-17 05:45 to
2018-12-17 08:15
lenght: 150 min.

intervention ID: 621
asset ID: 222289
intervention type: 7
failure mode: 7
expected duration: 67 min.
90%-quantile: 139 min.
mean costs: 745 Euro

shifted interventions:

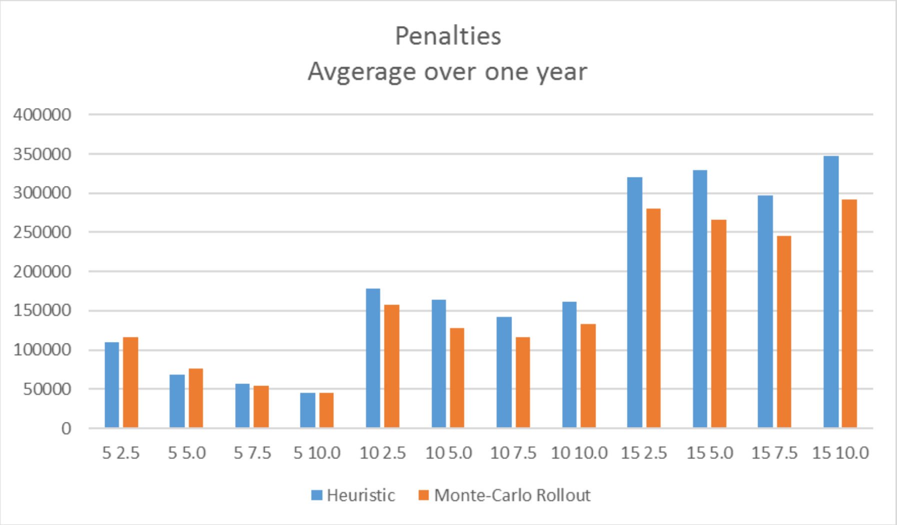
ID	0	on	1	with costs	962 EUR	repair time	71 min	penalties: service/shift	0	60	#feasible time slots: 4/5 (150)
ID	2563	on	15	with costs	962 EUR	repair time	71 min	penalties: service/shift	0	40	#feasible time slots: 4/4 (465)
ID	2190	on	3	with costs	962 EUR	repair time	71 min	penalties: service/shift	0	0	#feasible time slots: 5/6 (210)
ID	2215	on	25	with costs	981 EUR	repair time	51 min	penalties: service/shift	0	110	#feasible time slots: 8/8 (210)

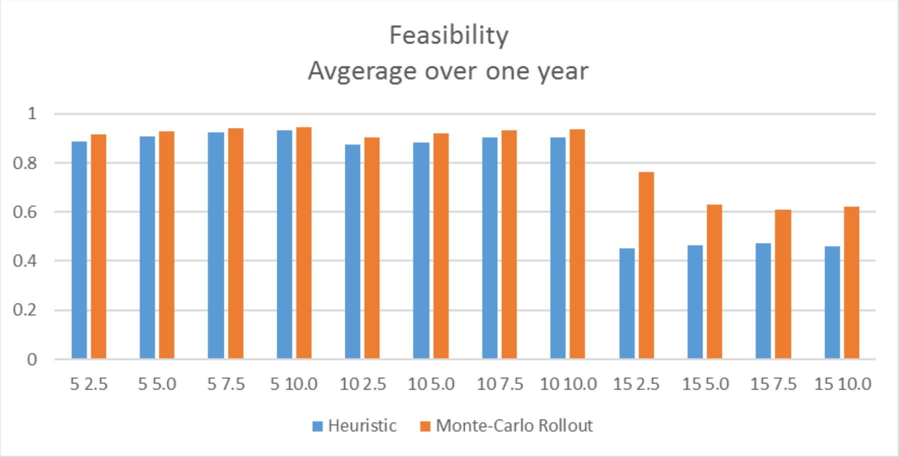
Railway Use case – Results

INFRALERT

Comparison with a Heuristic:

- Monte Carlo lower penalties and higher feasebility
- The more complicated the problem the higher is the advantage of the Monte Carlo method





Conclusion

We managed to…

- integrate uncertain information (e.g. duration of each intervention is only known at the time point of execution)
- make use of stochastic information
- ensure a robust planning

Road:

- avoid multiple traffic interruptions
- integrate traffic flow into the optimisation process

Rail:

- optimal intervention allocation to working teams
- reasonable usage of time windows

Outlook

Directions for future research…

- Generalisation and extension of the model to make it easily adaptable to other use cases
- Extend the scope to strategic planning
- Efficient data structures for the integration of Asset condition and Alert management
- Improving the runtime of the toolkit

INFRALERT

www.infralert.eu

Fraunhofer
IVI

Ute Kandler
Dipl.-Math.

ute.kandler@ivi.fraunhofer.de