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Regulating infrastructure network managers

Estimating and communicating infrastructure needs in uncertain environments

Presentation: Prof. Dr. Bryan T. Adey

Institute for Construction and Infrastructure management (IBI), ETH Zürich (ETHZ)

Overview

- Vision – a world where network regulators set performance objectives for network managers that are linked to the service they provide, and network managers are incentivized to provide this service
- Goal – to demonstrate using a relatively small, but realistic example how this is possible
- In the process – provide insight into the adjacent 6 questions

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

How should **performance objectives** for network operators be connected to the expected performance of the assets?

What role should **information** play in the setting of performance objectives and assessing if they have been met?

How can a better understanding of the condition of assets and **cost drivers** affect performance reviews?

How can **new technologies** be used to assess the condition and performance provided by assets?

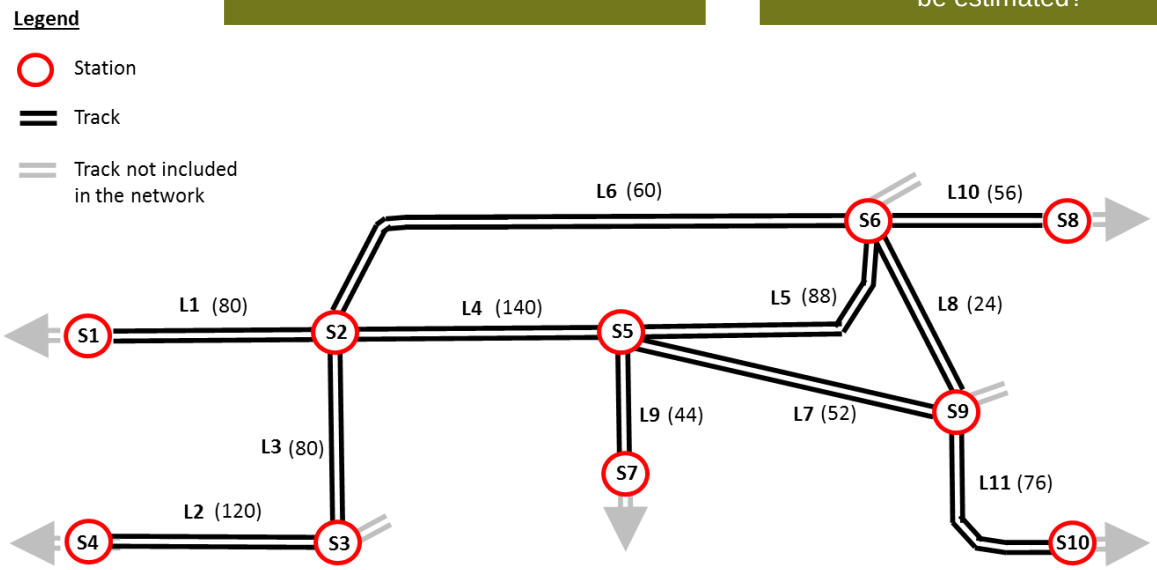
Infrastructure

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

The network consists of

- 86 bridges with a total deck surface area 20’076 m^2,
- 73 track sections measuring a total of 211’242 m length,
- 66 earthworks measuring a total of 360’261 m^3 and
- 130 switches.



Link	From-to	Trains per day	Link	From-to	Trains per day	Link	From-to	Trains per day
L1	S1-S2	80	L5	S5-S6	88	L9	S5-S7	44
L2	S4-S3	120	L6	S2-S6	60	L10	S6-S8	56
L3	S3-S2	80	L7	S5-S9	52	L11	S9-S10	76
L4	S2-S5	140	L8	S6-S9	24	N/A	N/A	N/A

Each train carries 100 passengers

Provide a complete description of the infrastructure

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

Object type		Unit	State	L7		L8		L9		L10		L11		Total	
				N	E	N	E	N	E	N	E	N	E	N	E
Bridge	Metal	m^2	**1**	0	0	1	208	4	785	0	0	0	0	13	1'564
			2	2	495	0	0	6	1'771	0	0	0	0	15	2'973
			3	0	0	1	104	1	154	3	373	0	0	10	1'074
			4	0	0	0	0	0	0	1	30	0	0	2	100
	..														
Track						4	447	1	65	2	19'464	1	0	23	38'768
						7	1'253	3	2'544	2	66	0	19'330	29	127'877
						3	1'217	0	0	0	0	1	521	17	35'431
						2	807	0						4	9'166
Earth-work	Emb me					1	2'414	3						6	12'325
						5	22'246	2	978	4	11'072	0	0	11	34'297
						2	13'126	2	15'783	2	4'754	0	0	8	41'399
						0	0	0	0	0	0	0	0	0	0
	..														
Switch	Turnout	number	**1**	3	[redacted]	8	[redacted]	0	[redacted]	2	[redacted]	4	[redacted]	40	[redacted]
			2	7	[redacted]	12	[redacted]	2	[redacted]	1	[redacted]	1	[redacted]	46	[redacted]
			3	4	[redacted]	10	[redacted]	1	[redacted]	1	[redacted]	2	[redacted]	39	[redacted]
			4	0	[redacted]	2	[redacted]	0	[redacted]	0	[redacted]	0	[redacted]	5	[redacted]

State now

Be complete

Infrastructure manager reports

Regulator checks

Right level of abstraction

Define clearly who and what is important

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

Stakeholder	Costs					
	Label	Description	Estimated by	Indicator	Unit	Unit cost (€/unit)
Owner	Interventions	the economic impact of material, machinery, and labour to execute interventions	the cost for manual labour, machinery, and materials listed on the final bills of executed interventions, i.e. cost of intervention	the type and extent of interventions executed	extent of inter-ventions	Depends on type
Users	Travel time	the econ… passeng…		…ne	minutes of additional travel time	0.5
	Accidents	the economic impact of having property damaged in an accident	the cost of repairing the damaged property	the extent of damaged property	number of accidents	100’000
		the societal impact of being injured in an accident	the number of injuries multiplied by the average amount that society is willing to pay to avoid being injured	the number of injuries	number of people	50’000
		the societal impact of being killed in an accident	the number of fatalities multiplied by the average amount the society is willing to pay to avoid being killed	the number of fatalities	number of people	1'000'000

Everyone and everything that is important

Agreement regulators and managers

Explain how system is to be modelled – How objects / required levels of service change

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

Object type		State at t	State at t+1			
			1	2	3	4
Bridge	Metal	1	0.95	0.05	0.00	0.00
		2	0.00	0.98	0.02	0.00
		3	0.00	0.00	0.97	0.03
		4	0.00	0.00	0.00	1.00
	Concrete	1	0.99	0.01	0.00	0.00
		2	0.00	0.97	0.03	0.00
		3	0.00	0.00	0.90	0.10
		4	0.00	0.00	0.00	1.00
	Masonry	1	0.94	0.06	0.00	0.00
		2	0.00	0.91	0.09	0.00
		3	0.00	0.00	0.95	0.05
		4	0.00	0.00	0.00	1.00
Tracks		1	0.70	0.30	0.00	0.00
		2	0.00	0.90	0.10	0.00
		3	0.00	0.00	0.84	0.16
		4	0.00	0.00	0.00	1.00

Object type		State at t	State at t+1			
			1	2	3	4
Earth-work	Embank-	1	0.85	0.15	0.00	0.00
		2	0.00	0.97	0.03	0.00
	Switc	3	0.00	0.00	0.70	0.30
		4	0.00	0.00	0.00	1.00

Deterioration

Probabilities of moving from one state to another in time intervals when there are no preventive interventions and no failures

All states covered

Explain how system is to be modelled – How objects / required levels of service change

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

Object type		Intervention type	State in which the intervention can be executed	Probabilities of object being in each state following intervention				Unit	Intervention Costs [€/unit]	Duration of traffic disruption [days/unit]
				1	2	3	4			
Bridge	Metal	Rehabilitation	3	0.80	0.20	0.00	0.00	m^2	3’000	0.080
		Renewal	all	1.00	0.00	0.00	0.00		5'000	0.100
	Concrete	Rehabilitation							1'000	0.060
		Renewal							7'500	0.120
	Masonry	Rehabilitation							1'000	0.080
		Renewal							8'000	0.150
Track		Rehabilitation							7.5	0.0001
		Renewal							750	0.0004
Earth-work	Embank-ment	Rehabilitation							400	0.008
		Renewal							3’000	0.008
	Cutting	Rehabilitation	3	0.80	0.20	0.00	0.00	m^3	400	0.008
		Renewal	all	1.00	0.00	0.00	0.00		3’000	0.02
Switch	Turnout	Rehabilitation	3	0.90	0.10	0.00	0.00	number	10’000	0.13
		Renewal	all	1.00	0.00	0.00	0.00		400’000	2.00

Improvement

Information to estimate intervention and travel time costs due to preventive interventions

All states
All interventions

Explain how system is to be modelled – How objects / required levels of service change

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

Object type		Unit	Intervention costs [€/unit]	Duration of traffic disruption [days/unit]
Bridge	Metal	m^2	4'000	0.097
	Concrete	m^2	3'000	0.073
	Masonry	m^2	2'000	0.098
Track		m	200	0.0002
Earthwork	Embankment	m^3	2'000	0.02
	Cutting	m^3	2'000	0.02
Switch	Turnout	number	45'000	0.45

Failures

Information to estimate owner costs of executing corrective interventions

Now all states and all interventions

Explain how system is to be modelled – How objects / required levels of service change

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

Object type		Unit	State	Probability of failure per unit	Probability of accident per failure	Probability of injury per accident per person in train	Probability of fatality per accident per person in train
Bridges	Metal	number	1	8×10^{-6}	0.3	0.8	0.2
			2	3×10^{-4}			
			3	5×10^{-3}			
			4	0.05			
	Concrete	number	1	2×10^{-6}	0.2	0.8	0.2
Track	Total	number	1			0.4	0.05
			2				
			3				
			4				
Earthwork	Embankment	number	1			0.4	0.05
			2				
			3				
			4				
	Cutting	number	1			0.2	0.005
			2				
			3				
			4				
Switches	Total	number	1	0.01	0.1	0.5	0.05
			2	0.10			
			3	0.25			
			4	0.50			

Failures

Information required to estimate the probabilities of failure and the costs of accidents

Now all states, all interventions, all costs

Explain how system is to be modelled – How future scenarios are determined

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

Object type	Strategy	State			
		1	2	3	4
Bridge	1	None	None	None	Renewal
	2	None	None	Rehabilitation	Renewal
Track	1	None	None	None	Renewal
	2	None	None	Rehabilitation	Renewal
Earthwork	1	None	None	None	Renewal
	2	None	None	Rehabilitation	Renewal
Switch	1	None	None	None	Renewal
	2	None	None	Rehabilitation	Renewal

All strategies

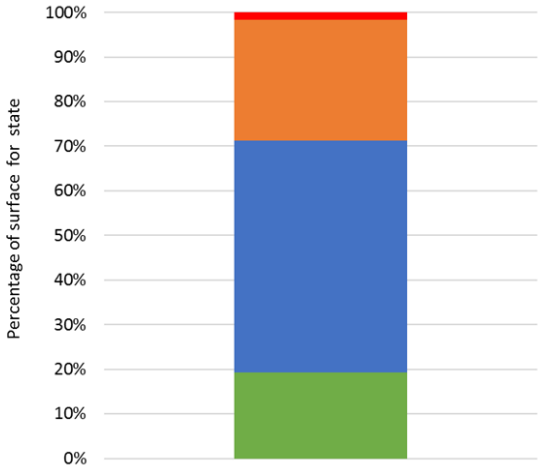
There should be nothing missing

Results: Average state of all objects per year

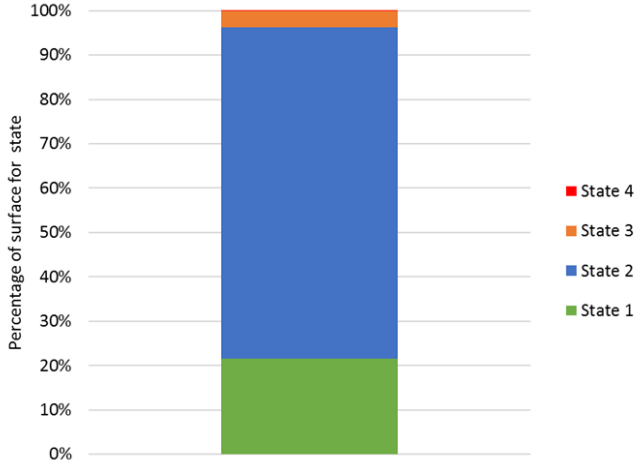
How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

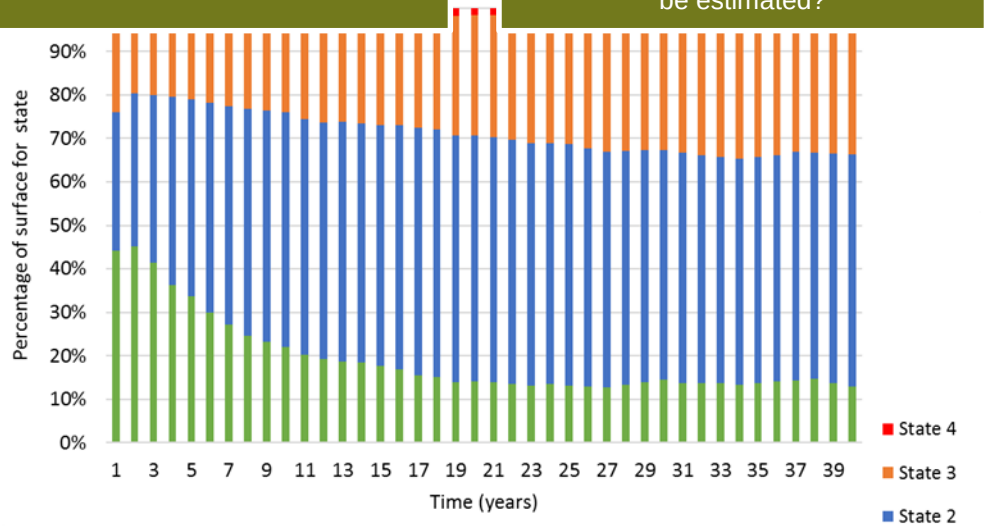
Strategy set 1



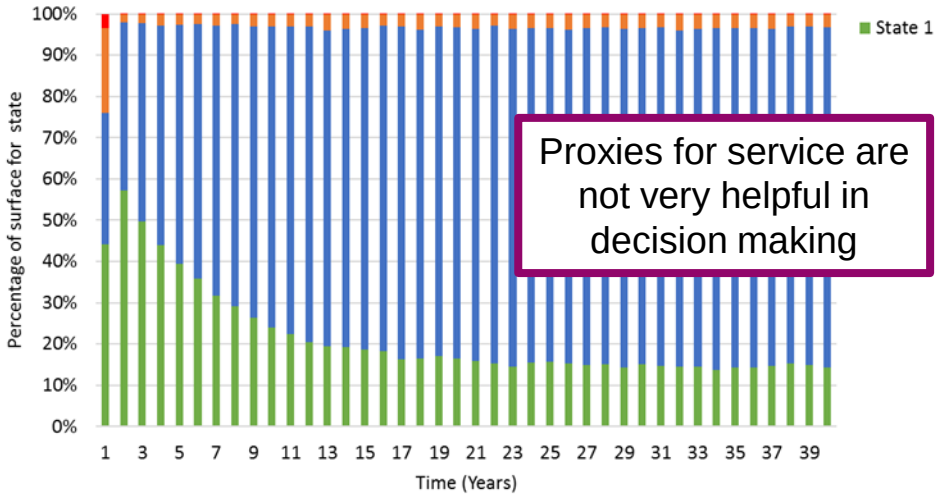
Strategy set 2



(a)



(b)



Proxies for service are not very helpful in decision making

Results: Total costs/risks – all objects

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

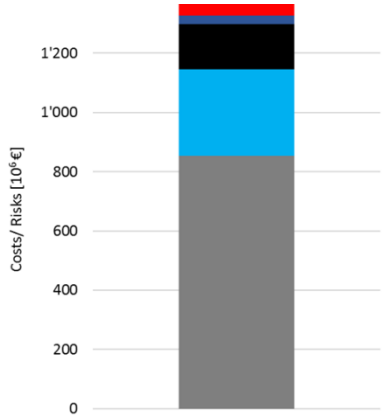
Stake-holder	Label	Costs/Risks	Estimation	Total costs/risks Strategy set 1 (10^6 €)	Total costs/risks Strategy set 2 (10^6 €)
Owner	Intervention	costs	$\sum_t^T C_{pi-i}$	854	228
		risks	$\sum_t^T R_{f-i}$	15	75
		total intervention costs/risks		1'005	303
	total owner costs/risks			1'005	303
Users	Travel time	costs	$\sum_t^T C_{pi-tt}$	293	357
		risks	$\sum_t^T R_{f-tt}$	30	10
		total travel time costs/risks		323	367
	Accident	costs	$\sum_t^T C_{pi-a}$	0	0
		risks	$\sum_t^T R_{f-a}$	45	40
		total accident costs/risks		45	40
	total user costs/risks			368	407

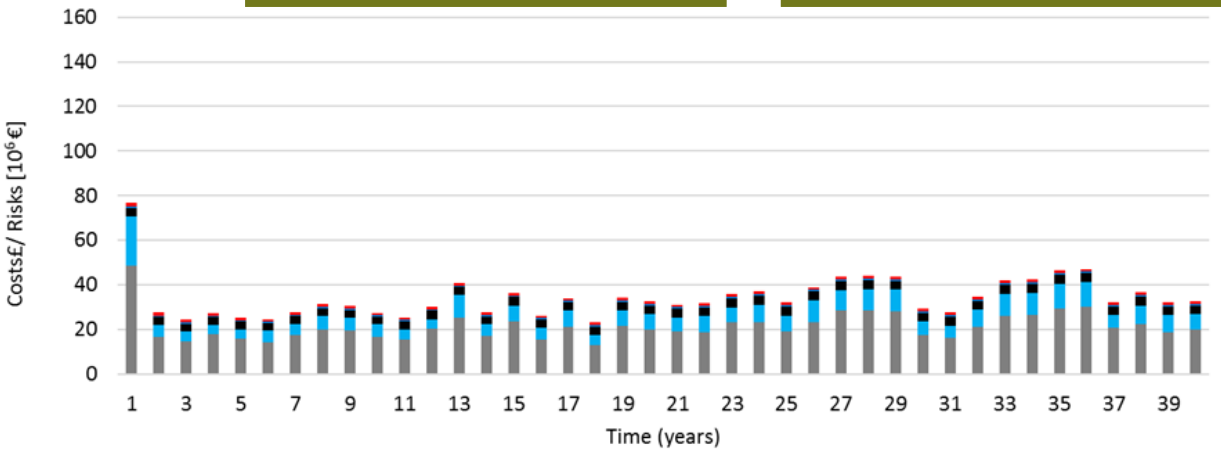
Results: Total costs/risks per cost/risk type

How should the **condition** of assets now and over time be estimated?

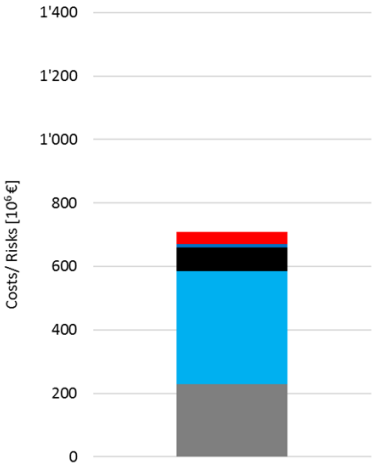
How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

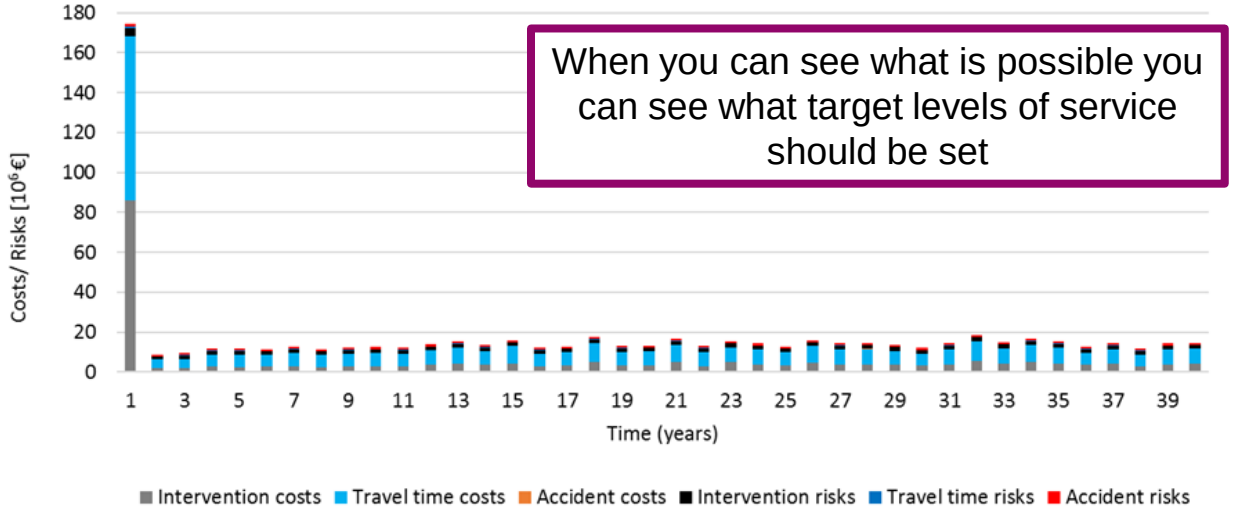
Strategy set 1





Strategy set 2





When you can see what is possible you can see what target levels of service should be set

Results: Total costs/risks – all objects

How should the **condition** of assets now and over time be estimated?

How should **expenditures** on maintenance and modification of the assets (due to deterioration and changing expectations taking into consideration changes in technologies) be estimated?

Object type		Strategy set 1 (10^6 €)			Strategy set 2 (10^6 €)		
		Costs	Risks	Total	Costs	Risks	Total
Bridge	Metal	25	3	28	35		
	Concrete	4	<1	5	2		
	Masonry	160	<1	161	162	<1	162
	Total	190	4	193	199	1	200
Tracks	Total	309	103	412	18	51	68
Earthwork	Embankment	178	30	207	103	7	111
	Cutting	422	50	472	251	8	260
	Total	600	79	679	355	16	370
Switch	Total	48	40	89	14	57	71
Total		1'147	226	1'373	585	125	710

You see where to focus efforts here!

Performance objectives for the next 40 years for total costs / risks

How should **performance objectives** for network operators be connected to the expected performance of the assets?

Stake-holder	Label	Costs/Risks	Estimation	Total costs/risks Strategy set 1 (10^6 €)	Total costs/risks Strategy set 2 (10^6 €)	Performance objective (10^6 €)
Owner	Intervention	costs	$\sum_t^T C_{pi-i}$	854	228	< 300
		risks	$\sum_t^T R_{f-i}$	15	75	< 100
		total intervention costs/risks		1'005	303	< 400
	total owner costs/risks			1'005	303	< 400
Users	Travel time	costs	$\sum_t^T C_{pi-tt}$	293	357	< 400
		risks	$\sum_t^T R_{f-tt}$	30	10	< 20
		total travel time costs/risks		323	367	< 400
	Accident	costs	$\sum_t^T C_{pi-a}$	0	0	0
		risks	$\sum_t^T R_{f-a}$	45	40	< 50
		total accident costs/risks		45	40	< 50
	total user costs/risks			368	407	< 450

Performance objectives for the next 40 years for total costs / risks per object

How should **performance objectives** for network operators be connected to the expected performance of the assets?

Object type		Strategy set 1 (10^6 €)			Strategy set 2 (10^6 €)			Performance objectives (10^6 €)		
		Costs	Risks	Total	Costs	Risks	Total	Costs	Risks	Total
Bridge	Metal	25	3	28	35	1	36	<40	<2	<42
	Concrete	4	<1	5	2	<1	2	<3	<1	<4
	Masonry	160	<1	161	162	<1	162	<200	<1	<200
	Total	190	4	193	199	1	200	<250	<11	<260
Tracks	Total	309	103	412	18	51	68	<20	<75	<95
Earthwork	Embankment	178	30	207	103	7	111	<150	<100	<250
	Cutting	422	50	472	251	8	260	<300	<15	<315
	Total	600	79	679	355	16	370	<450	<200	<600
Switch	Total	48	40	89	14	57	71	<20	<75	<95
Total		1'147	226	1'373	585	125	710	<700	<150	<850

Information to be collected depends on cost-benefit analysis

What role should **information** play in the setting of performance objectives and assessing if they have been met?

Object type		Strategy set 1 (10^6 €)			Strategy set 2 (10^6 €)			Performance objectives (10^6 €)		
		Costs	Risks	Total	Costs	Risks	Total	Costs	Risks	Total
Bridge	Metal	25	3	28	35	1	36	<40	<2	<42
	Concrete	4					2	<3	<1	<4
	Masonry	160					162	<200	<1	<200
	Total	190					200	<250	<11	<260
Tracks	Total	309	103	412	18	51	68	<20	<75	<95
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	Total	600	79	679	355	16	370	<450	<200	<600
Switch	Total	48	40					<20	<75	<95
Total		1'147	226					<700	<150	<850

Little information – large uncertainty = relatively high thresholds

Substantial information – little uncertainty = relatively low thresholds

Supervision / incentives are correlated with importance of objects

How can a better understanding of the condition of assets and **cost drivers** affect performance reviews?

Little supervision / incentives are required for objects that have little impact

Object type		S			2			Performance objectives (10^6 €)		
		Costs	Risks	Total	Costs	Risks	Total	Costs	Risks	Total
Bridge	Metal	25	3	28	35	1	36	<40	<2	<42
	Concrete	4	<1	5	2	<1	2	<3	<1	<4
	Masonry	160	<1	161	162	<1	162	<200	<1	<200
	Total	190	4	193	199	1	200	<250	<11	<260
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Switch	Total	48	40	89	14	57	71	<20	<75	<95
Total		1'147					710	<700	<150	<850

Substantial supervision / incentives are required for objects that have substantial impact

Update estimates / Evaluate performance / Re-evaluate conditions

How can **new technologies** be used to assess the condition and performance provided by assets?

Update estimates of
- state and state evolution
- proxies and proxy evolution
- optimal strategies
- expected costs and risks

These can in turn be used to evaluate if
- the network manager is following optimal strategies
- the base of the agreement between the regulator and manager needs to be adjusted, e.g. there is much faster deterioration than expected, or unforeseen new technologies have emerged that may yield substantial benefit.

	Masonry	160	<1	1						
	Total	190	4	1						
Tracks	Total	309	103	412	18	51	68	<20	<75	<95
Earthwork	Embankment	178	30	207	103	7	111	<150	<100	<250
	Cutting	422	50	472	251	8	260	<300	<15	<315
				679	355					<600
Switch				89	14					<95
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Keep track of realisation of costs and risks

Keep track of values of proxies, reliability, availability, safety, state

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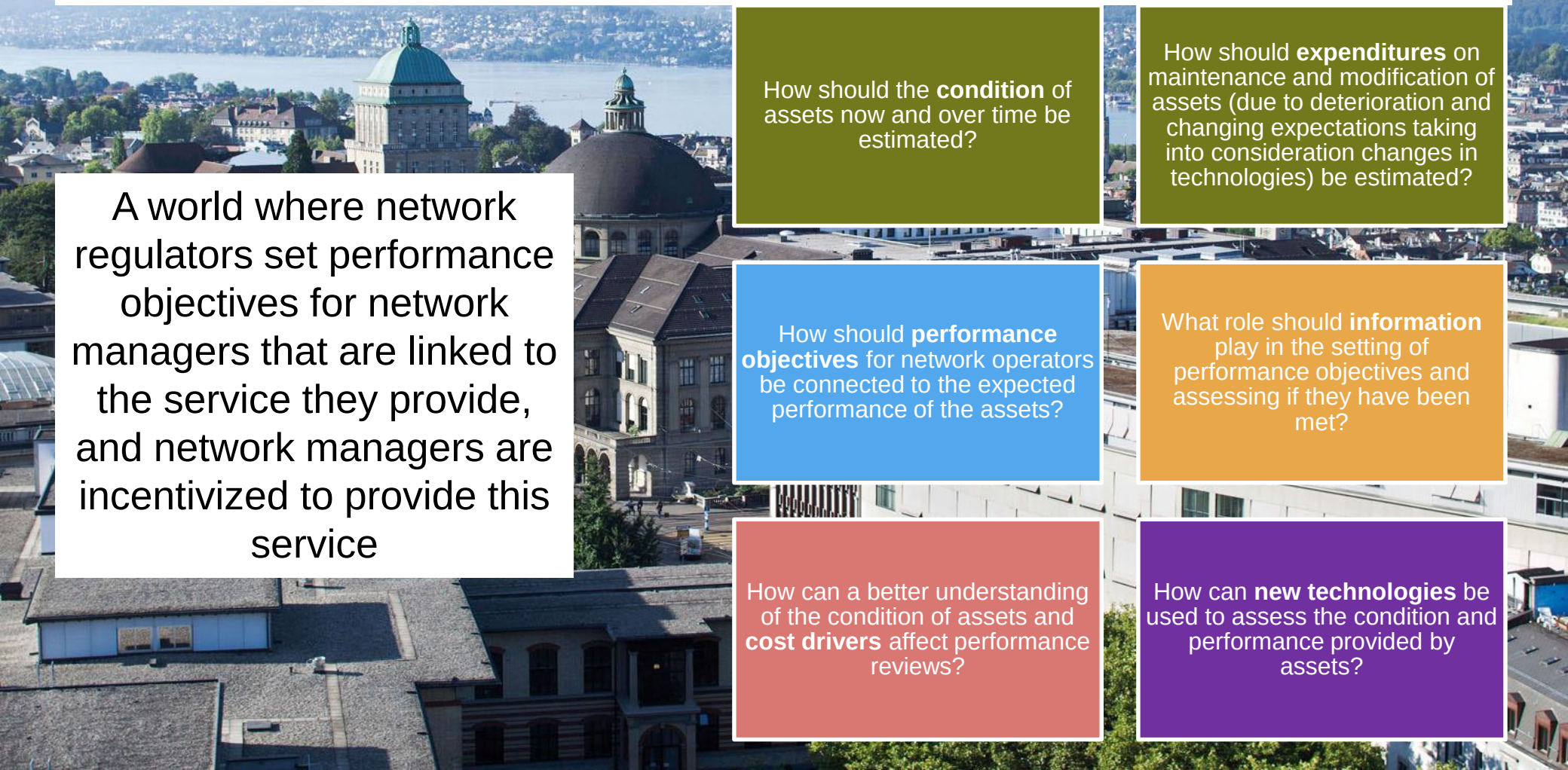
Estimating and communicating infrastructure needs in uncertain environments



A world where network regulators set performance objectives for network managers that are linked to the service they provide, and network managers are incentivized to provide this service

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