Capturing multimodal performance – KPI choices and trade-offs

Andrew Cook (Modus project & University of Westminster)

Passenger-centered mobility workshop

ART/ACARE/ISSNOVA/CAMERA

14 – 17 June 2021, on-line

Modus

SESAR JOINT UNDERTAKING

Founding Members

EUROPEAN UNION EUROCONTROL

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 891166.

Modus objectives and consortium

High-level objective of Modus to analyse how **performance of the overall European transport** system can be optimised by considering the entire **door-to-door journey holistically** and considering air transport within an **integrated, intermodal approach**

Understand
in a better way how ATM and air transport can better contribute to improve passengers' intermodal journeys and how this translates into an enhanced performance of the overall transport system

Explore and model
the connection and dependence between ATM/ air transport and other transport modes, with a special focus on the interplay between short and medium air and rail connections

Identify
the main barriers in achieving European (air) mobility goals and how air transport can evolve by efficiently connecting information and services with other transport modes to achieve the 4 hours door-to-door goal and a seamless journey experience for passengers.

https://modus-project.eu/

Call: ATM Role in Intermodal Transport (H2020-SESAR-ER4-10-2019)
Grant no. 891166
Duration: June 2020 – November 2022

(More on day 3)

Overview

- Indicator qualities and challenges
  - What indicators should do, and why it’s difficult
- Current frameworks
  - Comparing air and rail; intermodal context
- Capturing multimodal performance
  - Transformation and resilience
- Modus modelling context
  - Scenarios and use cases
- For discussion
  - (Breakouts)

Indicator qualities and challenges

Indicator qualities and challenges

User-friendly experience

Desirable qualities

Intelligible

- preferably to the point of being simple

Pertinent

- accurately reflect the aspect of performance being measured

Stable

- can't refine them from one period to another without losing comparability

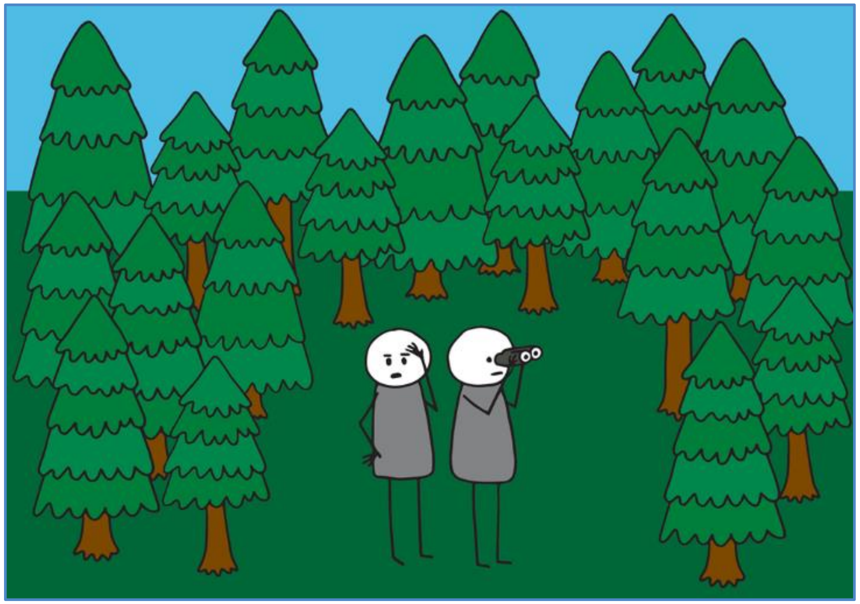
Sensitive

- a balance; functional specification (e.g. objective data) & scale (e.g. subjective data)

Some challenges

- indicators often limited by data availability (objective and subjective)
- may be difficult to respond to new data or methods, *and* maintain stability
- if (too) simple, may not afford the best understanding of system dynamics
- appropriate discriminatory power (pax cf. flights; types of pax; hubs cf. network)
- avoiding proliferation – adding new indicators only where added value is clear
- trade-offs between these desirable properties often necessary

Indicator qualities and challenges
Trees, woods, logs – user friendly?



	0	1	2	3	4	5	6	7	8	9	Mean Difference								
											1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
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60	7782	7789	7769	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9843	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

Current frameworks

Current frameworks
ICAO Global ATM operational concept ('Doc 9854')

KPA	Name	Meaning
1	**Access and equity**	"all airspace users have right of access to the ATM resources needed to meet their specific operational requirements [...] shared use of airspace by different users"
2	**Capacity**	"meet airspace user demands at **peak times** and locations while minimizing restrictions on traffic flow [...] **resilient** to service disruption"
3	**Cost effectiveness**	"cost of service [...] should always be considered when evaluating any proposal to improve ATM"
4	**Efficiency**	"airspace users want to depart and arrive at the times they select and fly the trajectory they determine to be optimum"
5	**Environment**	"contribute to the protection of the environment by considering noise, gaseous emissions and other environmental issues"
6	**Flexibility**	"ability of all airspace users to modify flight trajectories dynamically and adjust dep. & arr. times"
7	**Global interoperability**	"uniform principles [...] non-discriminatory global and regional traffic flows"
8	**Participation**	"ATM community [...] continuous involvement in the planning, implementation and operation"
9	**Predictability**	"ATM service providers to provide consistent & dependable levels of performance"
10	**Safety**	"highest priority [...] uniform safety standards [...] applied systematically"
11	**Security**	"protection against [...] intentional acts (e.g. terrorism) or unintentional acts (e.g. human error, natural disaster) "

Current frameworks
SES Performance Scheme: binding

RP	Effective	EU-wide binding KPIs (NB. Other PIs and monitoring are in place)			
		Safety	**Environment**	**Capacity**	**Cost efficiency**
1	**2012-2014** (en-route focus)	N/A	↑ Average horizontal en-route flight efficiency re. last-filed flight plan ("KEP") …	**Minutes of en-route ATFM delay: 0.5 min/flight**	**Average determined unit cost for e/r ANS** ↓ 3.2% p/a ("original" target; 2009-2014)
2	**2015-2019** (extended to gate-to-gate; safety added)	↑ Effectiveness of safety management (EoSM) & applying severity classification scheme, 2017 onwards	… & actual trajectory ("KEA")	(& *national* KPIs for airport ATFM arrival delay)	**Average determined unit cost for e/r ANS** (& national KPIs for ANS terminal cost efficiency)
3	**2020-2024** (pre-Covid-19 plans shown; not designed for traffic collapse; new PPs by OCT21; reach ATFM targets sooner)	Continued application of EoSM "levels"; a "counterbalance" w.r.t. capacity and cost efficiency	… KEA falling to 2.40%, for 2022-24 (KEP now downgraded to indicator, from KPI, so no targets. It was a KPI only in 2019.)	**Relaxed to 0.9 min/flight in 2020, falling to 0.5 by 2023**	New method with better baseline ↓ 1.9% 2.7% p/a

Current frameworks
European ATM MP (Ed. 2020): ambitions

FIGURE 10. PERFORMANCE AMBITIONS FOR 2035 FOR CONTROLLED AIRSPACE

Key performance area	SES high-level goals 2005	Key performance indicator	Performance ambition vs. baseline: Baseline value (2012)	Ambition value (2035)	Absolute improvement	
Capacity	Enable 3-fold increase in ATM capacity	**Departure delay**[4], min/dep	9.5 min	6.5-8.5 min	1-3 min	
		IFR movements at most congested airports[5], million	4 million	4.2-4.4 million	0.2-0.4 million	
		Network throughput IFR flights[5], million	9.7 million	~15.7 million	~6.0 million	
		Network throughput IFR flight hours[5], million	15.2 million	~26.7 million	~11.5 million	
Cost efficiency	Reduced ATM services unit costs by 50% or more	**Gate-to-gate direct ANS cost per flight**[1] EUR(2012)	EUR 960	EUR 580-670	EUR 290-380	
Operational efficiency		**Gate-to-gate fuel burn per flight**[2], kg/flight	5280 kg	4780-5030 kg	250-500 kg	5-10%
		Additional [illegible], min/flight Within the: Gate-to-gate flight time per flight[3], min/flight	8 [illegible] (111 min)	[illegible]7-4 min (116 min)	[illegible]4.5 min	[illegible]
Environment	Enable [illegible] the effects flights have on the environment	**Gate-to-gate CO_2 emissions**, tonnes/flight	16.6 tonnes	15-15.[illegible] tonnes	0.8-1.6 tonnes	5-10%
Safety	Improve safety by factor 10	**Accidents with direct ATM contribution**[6], #/year Includes in-flight accidents as well as accidents during surface movement (during taxi and on the runway)	0.7 (long-term average)	no ATM related accidents	0.7	100%
Security		**ATM related security incidents resulting in traffic disruptions**	unknown	no significant disruption due to cyber-security vulnerabilities	unknown	-

1 Unit rate savings will be larger because the average number of Service Units per flight continues to increase.
2 "Additional" means the average flight time extension caused by ATM inefficiencies.
3 Average flight time increases because the number of long-distance flights is forecast to grow faster than the number of short-distance flights.
4 All primary and secondary (reactionary) delay, including ATM and non-ATM causes.
5 Includes all non-segregated unmanned traffic flying IFR, but not the drone traffic flying in airspace below 500 feet or the new entrants flying above FL 600
6 In accordance with the PRR definition: where at least one ATM event or item was judged to be DIRECTLY in the causal chain of events leading to the accident. Without that ATM event, it is considered that the accident would not have happened.

2035: average dep. delay: 6.5-8.5 mins/flight (upper: 32% improvement)

Current frameworks
KPIs for Shift2Rail JU


CONSOLIDATED
ANNUAL ACTIVITY REPORT 2019
22 June 2020

TABLE III - Key Performance Indicators specific for the S2R JU

#	Key Performance Indicator	Objective	Data to be provided by	Baseline at the start of H2020	Target at the end of H2020	Automated	Result 2019
			S2R				
1	% reduction in the costs of developing, maintaining, operating and renewing infrastructure and rolling stock and increase energy efficiency compared to "State-of-the-art"	Reduce the life-cycle cost of the railway transport system	JU	"State-of-the-art" 2014	> 50 %	No	See table IV
2	% increase the capacity of railway segments to meet increased demand for passenger and freight railway services compared to "State-of-the-art" 2014	Enhance the capacity of the railway transport system	JU	"State-of-the-art" 2014	100%	No	See table IV
3	% decrease in unreliability and late arrivals compared to "State-of-the-art" 2014	Increase in the quality of rail services	JU	"State-of-the-art" 2014	> 50%	No	See table IV
4	Reduce noise emissions and vibrations linked to rolling stock and respectively infrastructure compared to "State-of-the-art" 2014	Reduce the negative externalities linked to railway transport	JU	"State-of-the-art" 2014	> 3 - 10 dBA	No	-2 dB overall noise limits (FINE1) -4 dB parking operation (FINE1)

Shift2Rail, Consolidated annual activity report 2019 (2020) (p. 194)

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Current frameworks
KPIs for Shift2Rail JU

(Life cycle cost)

SPD	LCC		Capacity		Punctuality	
Target	-50%		+100%		+50%	
High speed	-15%	-18%	69%	74%	29%	19%
Regional	-21%	-24%	57%	49%	51%	15%
Urban	-16%	-18%	23%	28%	n / a	
Freight	-39%	-40%	42%-114%*	91%	78%	71%

*depending on IP2 improvement 0-50%

release 1.0

- "The KPI **reliability** and **punctuality** is measured as a 50% decrease of late arrivals mainly caused by unreliability of technologies"
- Technologies evaluated w.r.t. 4 scenarios called System Platform Demonstrators (SPDs)
- With technology demonstrators within 5 Innovation Programmes (IPs): defined in S2R MP
- Only EU binding regulations for rail are w.r.t. **safety** and **interoperability**

Capturing multimodal performance

Capturing multimodal performance “Lessons learned”

Modus SESAR JOINT UNDERTAKING

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87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
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96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9843	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

Capturing multimodal performance
Setting priorities, trade-offs

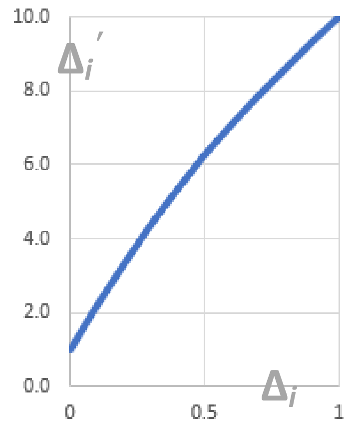
KPA	Air	Rail	Intermodal	
			Cooperative	Trade-off
Capacity	µ Arrival delay (airport) [per pax]	µ Arrival delay (station) [per pax]	D2D	
Predictability	1/σ [or tail] Arrival delay (airport) [per pax]	1/σ [or tail] Arrival delay (station) [per pax]	D2D	
Environment	Σ CO_2 [network]	Σ CO_2 [network]	D2D	

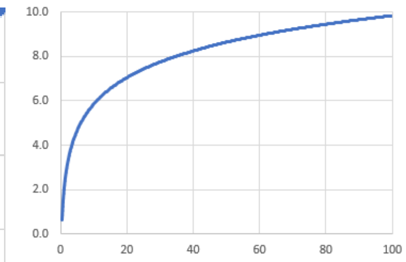
Capacity ↑ Predictability ↑ Environment ↓ (Cost ↑) (interdependencies)
Need to monetise as much as possible (high-level ambitions, cascade into indicators)

Capturing multimodal performance Transformation

$$\Delta_i' = m\ln(\Delta_i + \tau) + k$$

‘Telescoping’ transformation
1-10 scale, ‘early’ sensitivity
5 is your target (SESAR 32%), more intuitive





(as %)

Δ_i	Δ_i'
0.005	1.0
0.05	1.6
0.1	2.2
0.2	3.3
0.3	4.4
0.4	5.3
0.5	6.2
0.6	7.1
0.7	7.9
0.8	8.6
0.9	9.3
1	10.0

$$\text{Trade-off} = \frac{\Delta_R' w_R}{\Delta_A' w_A}$$

Significance testing required
Bootstrapping often a good bet
Strip out the non-significant values

Capturing multimodal performance
Types of resilience

Journal of Air Transport Management 56 (2016) 38–47

Contents lists available at ScienceDirect

Journal of Air Transport Management

journal homepage: www.elsevier.com/locate/jairtraman

Measuring the cost of resilience

Andrew Cook [a,*], Luis Delgado [a], Graham Tanner [a], Samuel Cristóbal [b]

[a] Department of Planning and Transport, University of Westminster, London, United Kingdom
[b] The Innaxis Foundation and Research Institute, Madrid, Spain

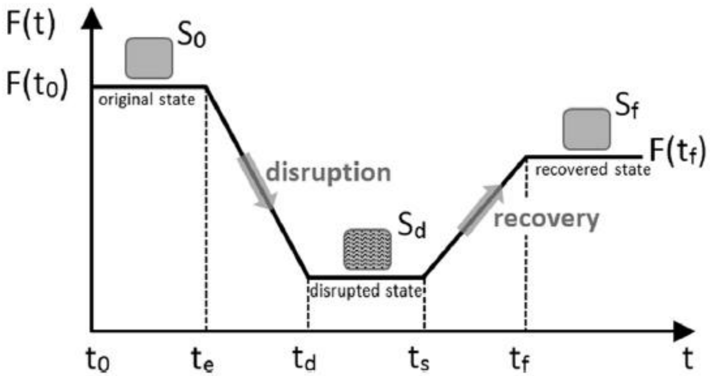


Fig. 1. State diagram. Source: adapted from Henry and Ramirez-Marquez (2012).

Table 3
Three major definitions of resilience.

Terminology	Introduction	Field	State(s)	Key feature
Engineering resilience	Hoffman (1948)	material testing	one stable state	inherent ability of the system to return to its original state
Ecological resilience	Holling (1973)	ecology	multiple states	ability of the system to absorb disturbance
Resilience engineering	Hollnagel et al. (2006)	air transport	multiple states	safety-based design of socio-technical systems

Table 4
Three capacities of resilience.

Capacity	Key feature	Key association(s)	ATM focus
Absorptive	network can withstand disruption	robustness; little or no change may be apparent	strategic
Adaptive	flows through the network can be reaccommodated	change is apparent; often incorporates learning	strategic and/or tactical
Restorative	recovery enabled within time and cost constraints	may focus on dynamics/targets; amenable to analytical treatment	tactical

Capturing multimodal performance
Cost of resilience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cost of disruption with mechanism

investment running cost

$$R_C = \frac{\sum_u^d C_u(t) \; - \; \sum_u^d \sum_u^m C_u(t) \; - \; C_m(t)}{\sum_u^d C_u(t)}$$

disruption cost

flights; passengers; mode

$R_C \leq 1$

Measures the effect of an investment mechanism w.r.t. the cost of disturbance without the mechanism: **R_c = 1** complete cost recovery; **R_c = 0** no cost recovery.
NB. Small numbers at network level: improved pax wait rules, **R_c = 0.06**

Modus modelling context

Modus modelling context
Scenarios and use cases

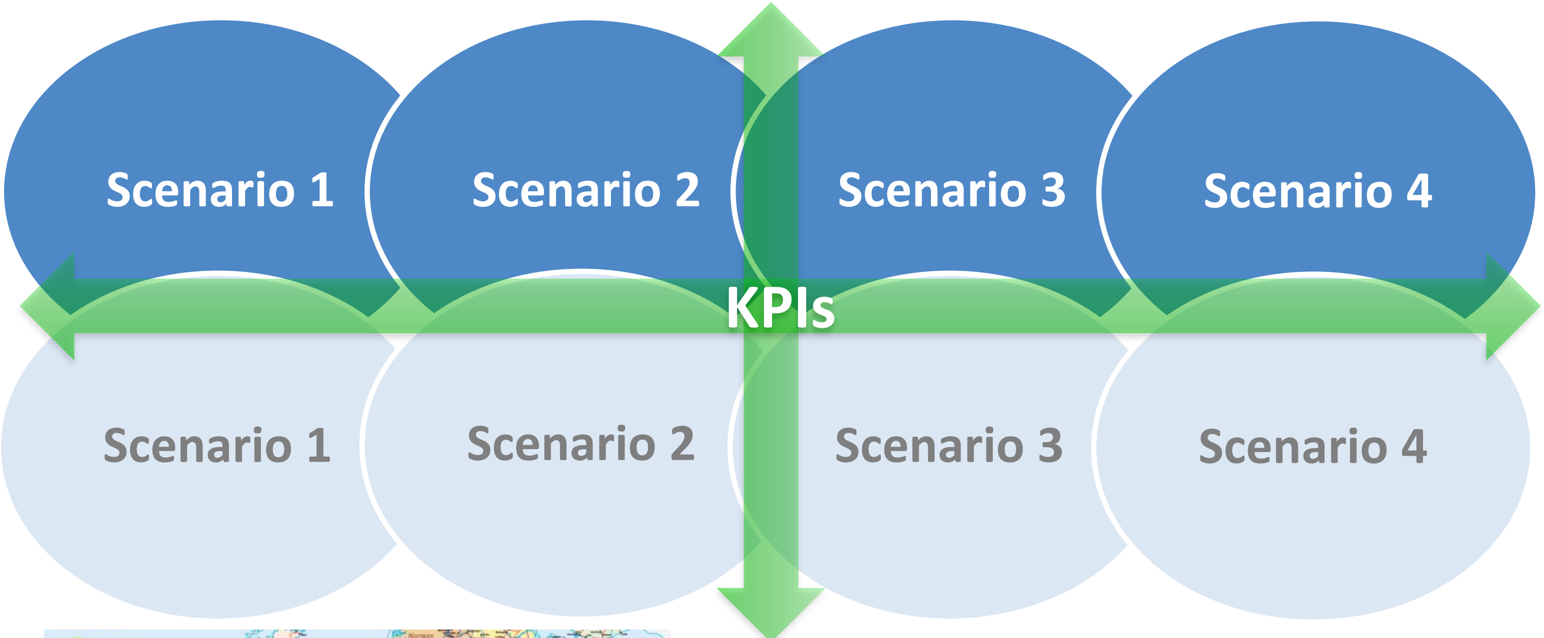
- **Global Growth:** Strong global growth with technology used to mitigate sustainability challenges;
- **Regulation and Growth** (Most-Likely): moderate growth regulated to reconcile demand with sustainability issues;
- **Fragmenting World:** a World of increasing tensions and reduced globalisation;
- **Happy Localism:** like *Regulation and Growth*, but with a fragile Europe increasingly, and contentedly, looking inwards.

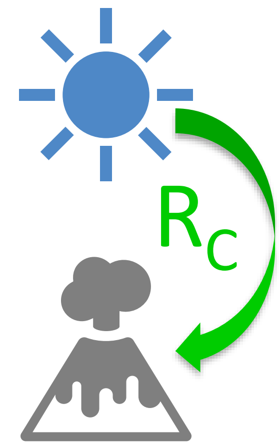
Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4

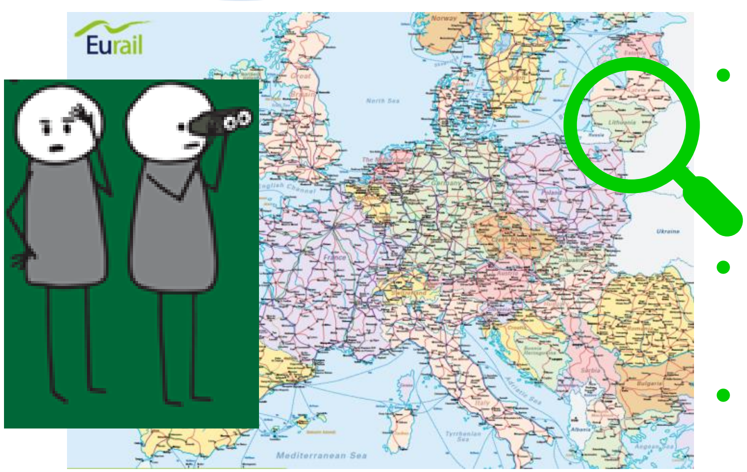
Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4

(Especially rail cf. air provision, e.g. extended short-haul restrictions; pax behaviour)

Modus modelling context
Scenarios and use cases







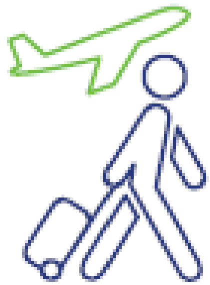
- **Use cases** – e.g. service recovery at five hubs, across scenarios: two of which have enhanced ticketing interoperability
- **Node-centric** – e.g. (loss of) intermodal centrality; cf. IMHOTEP: A-CDM intermodal integration
- **Absorptive & adaptive** resilience – challenge identifying input costs

Capturing multimodal performance

For discussion

Capturing multimodal performance
For discussion

Modus SESAR JOINT UNDERTAKING



Efficient multimodal disruption management will also minimise the impact on passengers. Furthermore, a connectivity indicator will show progress towards enabling better connectivity for European citizens.

Passenger experience

- In terms of development, support to airspace users is required on the definition and validation of new operational and social indicators.

Flightpath 2050 Europe's Vision for Aviation

Serving society's needs

- **Meeting societal and market needs for affordable, sustainable, reliable and seamless connectivity for passengers and freight with sufficient capacity**

(trade-offs?)

Generalised cost = monetary + non-monetary

$€_{ticket}$ + $€_{time}$ (D2D, productive, waiting ...) + $€_{\sigma}$ + €...

Connectivity

D2D? Intra-city? Intra-node? Cost? Time? Frequency? Reliability? Ease? Choice? ...

Thank you

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 891166.

Stay in touch with us www.modus-project.eu

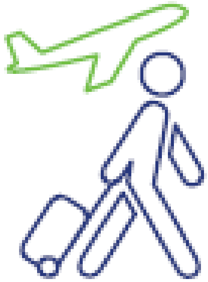
#modus_eu

Modus

SESAR JOINT UNDERTAKING

Capturing multimodal performance
For discussion

Modus SESAR JOINT UNDERTAKING



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CAMERA
COORDINATION AND SUPPORT ACTION FOR MOBILITY IN EUROPE
Research and Assessment

MOBILITY REPORT 1

Interoperability	Transition-journey ratio: average of (time spent during transitions / total travel time for the journey)
	Security efficiency: average of (time spent in security checks / total travel time for the journey)
Flexibility	Percentage of delayed journeys reconfigured
	Percentage of delayed journeys where all alternative travel options covering the entire itinerary are automatically sent to connected passengers

Capturing multimodal performance
‘Telescoping’ transformation

sets upper output score of 10

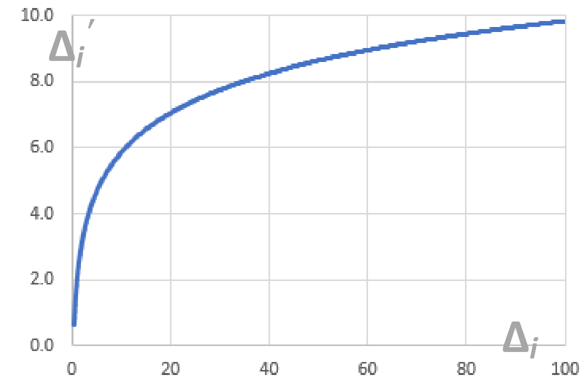
lower output score (1.0)

$$\Delta_i' = m \ln(\Delta_i + \tau) + k$$

transformed output score

sets lower input threshold (τ =1-**0.5**)

(NB. The plot shows transformed *percentages*)



Δ_i (%)	Δ_i'
0.5	1.0
5	4.3
10	5.6
20	6.9
30	7.7
40	8.2
50	8.7
60	9.0
70	9.3
80	9.6
90	9.8
100	10

Capturing multimodal performance Bootstrapping

Bootstrapping is a non-parametric technique used to estimate the distribution of an important statistic such as an incremental cost-effectiveness ratio (ICER) from a population sample such as a clinical trial. Random samples of the same size as the original sample are drawn with replacement from the data source. The statistic of interest is calculated from each of these resamples, and these estimates are stored and collated to build up an empirical distribution for the statistic, for which measures of central tendency (mean, median) and spread (confidence intervals) are obtained. Typically, 1000 or more bootstrap samples are required. In the case of ICERs generated from clinical trial or observational data it is important to generate pairs of values (for costs and effects) for each treatment alternative in the same re-sample. The term 'bootstrapping' refers to the apparently impossible achievement of pulling oneself up by ones own bootstraps: 'parametric' equations for sampling distributions, which may be difficult to estimate (for example for ICERs), are not required and instead, the data replies on its own observations. The central and important assumption is that the study sample is an accurate representation of the full population. A number of methods (for example: 'percentile, 'bias corrected') have been developed to estimate confidence intervals from bootstrapped samples in different circumstances, including meta-analyses from more than one dataset.

How to cite: Bootstrapping [online]. (2016). York; York Health Economics Consortium; 2016. https://yhec.co.uk/glossary/bootstrapping/