Driver schedule efficiency vs. public transport robustness:

A framework to quantify this trade-off based on passive data

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July 24th, 2018

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Relevance: complex driver schedules

- Public transport driver schedules increasingly complex:
  - Driver Scheduling Problem (DSP) well-known topic in OR
  - Push for higher efficiency in PT operations
  - More advanced scheduling software (e.g. HASTUS) available

Single-line single-vehicle
Duty: 1 line, 1 vehicle

Dienst: **48151** ZO — 03/04/2017 — Den Haag, Centraal Station — HTM

Start: 10:34	Einde: 17:48	Lengte: 6h43	Spread: 7h13

Lijn	Code	Vertrek	Van	Naar	Aankomst
6	02	10:34	CSt2	LGe1	10:53
6		10:56	LGe1	LNo1	11:34
		11:34	Rustmoment		11:45
6	02	11:45	LNo1	LGe1	12:23
6		12:26	LGe1	LNo1	13:07
6		13:15	LNo1	LGe1	13:55
6		13:58	LGe1	LNo1	14:39
		14:39	Pauze		15:15
6	02	15:15	LNo1	LGe1	15:55
6		15:58	LGe1	LNo1	16:39
6		16:45	LNo1	LGe1	17:25
6		17:28	LGe1	CSt3	17:48

Driver schedule complexity

Fictitious example

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Single-line multi-vehicle

Duty: 1 line, >1 vehicle

Dienst: **48153** ZO

03/04/2017

Remise Lijsterbes

HTM

Start: 15:28	Einde: 22:16	Lengte: 6h17	Spread: 6h47

Lijn	Code	Vertrek	Van	Naar	Aankomst
MAT/CAR	41	15:28	RVL	LGe1	15:40
	Voertuigwissel (aankomst VT: 15:40)				
6	03	15:43	LGe1	LNo1	16:24
6		16:30	LNo1	LGe1	17:10
6		17:13	LGe1	LNo2	17:53
		17:53	Pauze		18:30
6	03	18:30	LNo2	LGe1	19:08
6		19:11	LGe1	LNo1	19:50
		19:50	Rustmoment		20:15
	Voertuigwissel (aankomst VT: 20:15)				
6	02	20:15	LNo1	LGe1	20:53
6		20:56	LGe1	LNo2	21:36
MAT/6		21:36	LNo2	RVL	22:10
		22:10	Wagen Wegz.		22:16

Driver schedule complexity

Fictitious example

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Relevance: complex driver schedules

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Multi-line multi-vehicle

Duty: >1 line, >1 vehicle

Dienst: 48150 ZO	Remise Lijsterbes HTM		
03/04/2017			
Start: 10:29	Einde: 18:46	Lengte: 7h47	Spread: 8h17

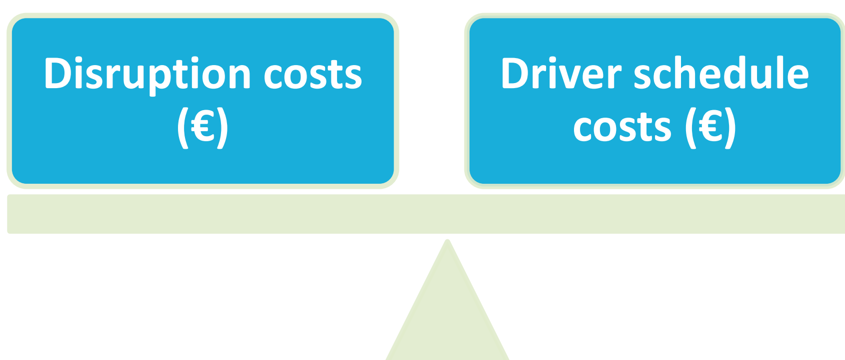
Lijn	Code	Vertrek	Van	Naar	Aankomst
		10:29	Wagen Klaarm.		10:39
MAT/6	07	10:39	RVL	LNo2	11:15
6		11:15	LNo2	LGe1	11:53
6		11:56	LGe1	LNo2	12:34
		12:34	Rustmoment		12:45
6	07	12:45	LNo2	LGe1	13:25
6		13:28	LGe1	LNo2	14:09
		14:09	Pauze		14:45
6	07	14:45	LNo2	LGe1	15:25
6		15:28	LGe1	LNo1	16:09
6		16:15	LNo1	LGe1	16:55
		Voertuigwissel			
MAT/CAR	41	16:57	LGe1	RVL	17:09
		17:09	Rustmoment		17:31
		17:31	Lopen RVL-GoS2		17:41
		Voertuigwissel (aankomst VT: 17:41)			
12	01	17:41	GoS2	DuD1	17:48
12		17:56	DuD1	RwP1	18:21
MAT/12		18:21	RwP1	RVL	18:40
		18:40	Wagen Wegz.		18:46

Driver schedule complexity

Fictitious example

Study objective

- Problem statement:
  - More complex driver schedule *reduces* operator costs during undisrupted situations
  - More complex driver schedule *increases* disruption costs
  - Impact of driver schedule on disruption costs hardly considered
- Development of framework which integrates driver schedule and PT disruption costs:
  - Quantify both components → express in same monetary units
  - Quantify PT disruption costs as function of driver schedule type



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Integrated framework

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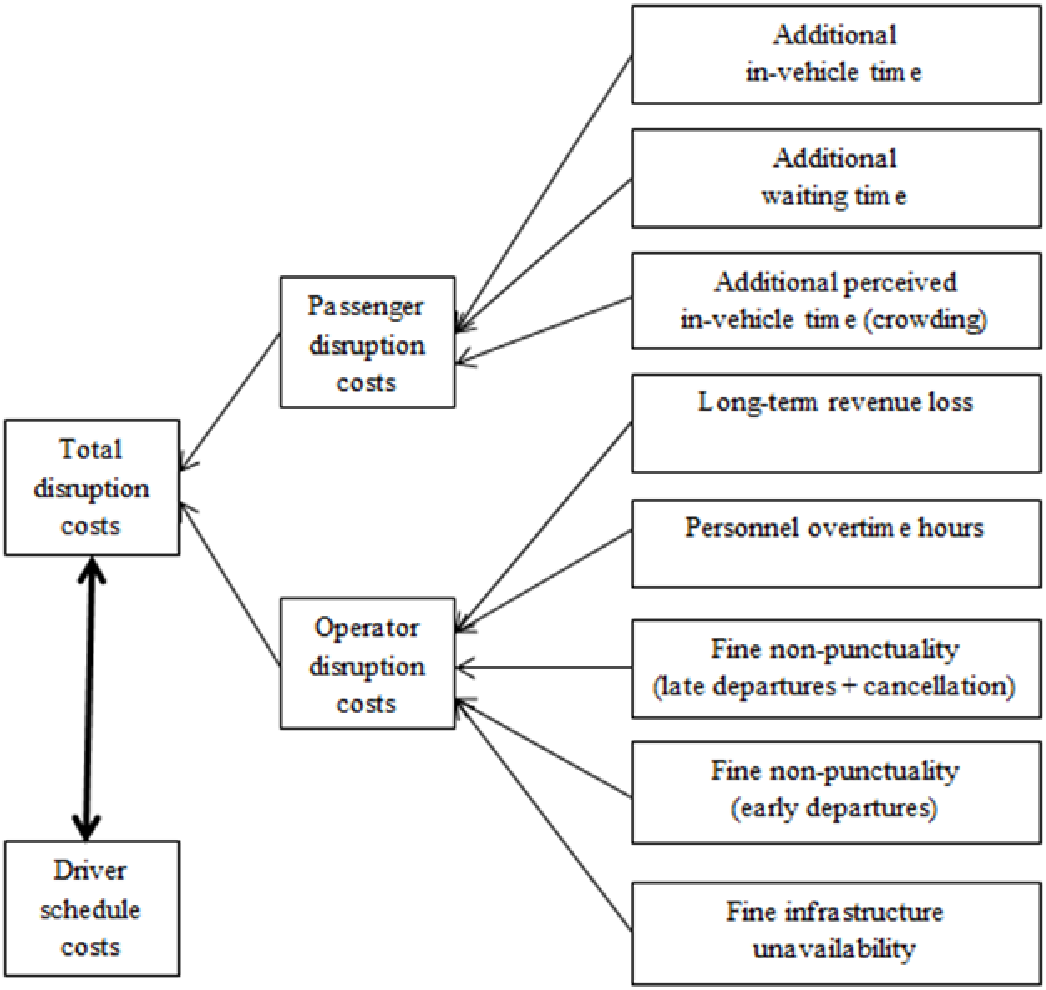

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Passenger disruption costs (1)

- In-vehicle time $\triangle t^{ivt}$:
  - Disrupted link from stop s_l to stop s_{l+1}
  - Additional running time compared to schedule for each run r
  - Multiplied by passenger flow q_{rs_l}

$$\triangle t^{ivt} = \sum_{r \in R} \left(\left(\left(t^a_{rs_{l+1}} - \tilde{t}^a_{rs_{l+1}} \right) - \left(t^d_{rs_l} - \tilde{t}^d_{rs_l} \right) \right) * q_{rs_l} \right) * VoT$$

- Waiting time $\triangle t^{wtt}$:
  - Use PRDM to express service irregularity (Van Oort & Van Nes 2009)
  - Average waiting time compared to scheduled waiting time
  - For each hour of the day h; multiplied by coefficient β_1

$$\triangle t^{wtt} = \sum_{h \in H} \left(\left(\frac{60}{2 * f^h_l} \right) * \left(1 + (PRDM^{h^2}) \right) - \left(\frac{60}{2 * \tilde{f}^h_l} \right) \right) * \beta_1 * VoT$$

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Passenger disruption costs (2)

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- Perceived in-vehicle time due to crowding $\triangle\, t^{ivt,p}$:
  - Multiplication of realized in-vehicle time with crowding multiplier
  - Compare between disrupted case i and undisrupted case $j \neq i$

$$\triangle\, t^{ivt,p} = \sum_{r^h \in R^h} \sum_{s_{l,1} \in s_{l,|l|}} \left(\left(q_{rs}^{i} * \left(t_{rs+1}^{a} - t_{rs}^{d} \right) * \gamma_{rs} \right) - \left(q_{rs}^{j \neq i} * \left(t_{rs+1}^{a} - t_{rs}^{d} \right) * \gamma_{rs} \right) * VoT \right.$$

- Calculation of crowding multiplier γ_{rs} (Wardman & Whelan 2010):
  - Based on seat capacity φ_r^s and crush capacity φ_r^c
  - Increases linearly based on corresponding multipliers γ_r^s and γ_r^c

$$\gamma_{rs} = \begin{cases} 0.95 & if\ q_{rs} \leq 0.5 * \varphi_r^s \\ 0.95 + \left(\dfrac{q_{rs} - 0.5 * \varphi_r^s}{0.5 * \varphi_r^s} \right) * \left(\gamma_r^s - 0.95 \right) & if\ 0.5 * \varphi_r^s < q_{rs} < \varphi_r^s \\ \gamma_r^s + \left(\dfrac{q_{rs} - \varphi_r^s}{\varphi_r^c - \varphi_r^s} \right) * \left(\gamma_r^c - \gamma_r^s \right) & if\ q_{rs} > \varphi_r^s \end{cases}$$

Operator disruption costs

- Long-term loss of ridership Δq (Van Oort et al. 2015):
  - Approach based on simple generalized cost elasticity E_d
  - Weighted average generalized costs $\bar{t}^{pi}$ between disrupted time t^i and undisrupted time $T - t^i$

$$\Delta q = \left(E_d * \left(\frac{\bar{t}^{pi} * t^i + \left(\bar{t}^{pj \neq i} * \left(T - t^i \right) \right)}{\bar{t}^{pj \neq i} * T} - 1 \right) + 1 \right) * \sum_{s_i \in S_i} \sum_{s_j \in S_j} q_{s_i, s_j}$$

- Components operator costs c_o^i:
  - Revenue loss: $\beta_2 * \Delta q$
  - Personnel overtime hours costs: $\beta_3 * t$
  - Fine too early, too late and cancelled trips:

    $\beta_4 * \sum_{r \in R} r^e + \beta_5 * \sum_{r \in R} r^l + \beta_6 * \sum_{r \in R} r^c$
  - Fine infrastructure unavailability: $\beta_7 * t^i$

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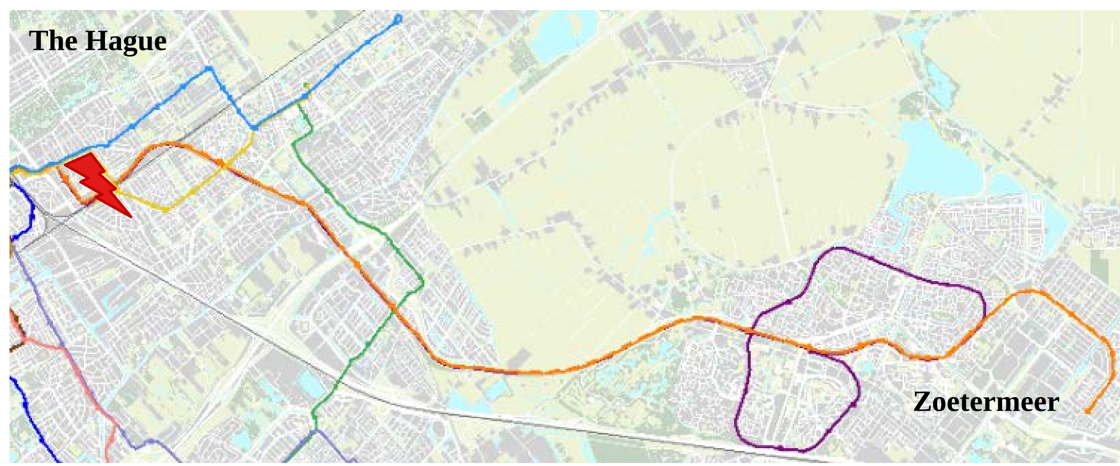
Case study: disruption

- Case study: urban PT network The Hague, the Netherlands
- Switch failure light rail at Laan van NOI station:
  - o 11:22 – 11:26: activation rescheduling procedure
  - o 11:26 – 14:33: active rescheduling procedure during disruption
  - o 14:33 – 19:38: service recovery after disruption resolved



Case study: driver schedules

- Scenario 1: multi-line multi-vehicle driver schedule:
  - Schedule-based rescheduling
  - Situation as currently applied by PT operator
  - Empirical quantification based on (fusion of) AFC + AVL data
- Scenario 2: single-line multi-vehicle driver schedule:
  - Headway-based rescheduling: no risk on delay propagation
  - Shorter recovery time → reduction disruption costs + overtime
  - Quantification based on equal hourly vehicle distribution
    - Same irregularity (PRDM) as during undisrupted case
    - Passenger load equally divided by *perceived* frequency
- Extrapolation to yearly costs based on disruption log-data

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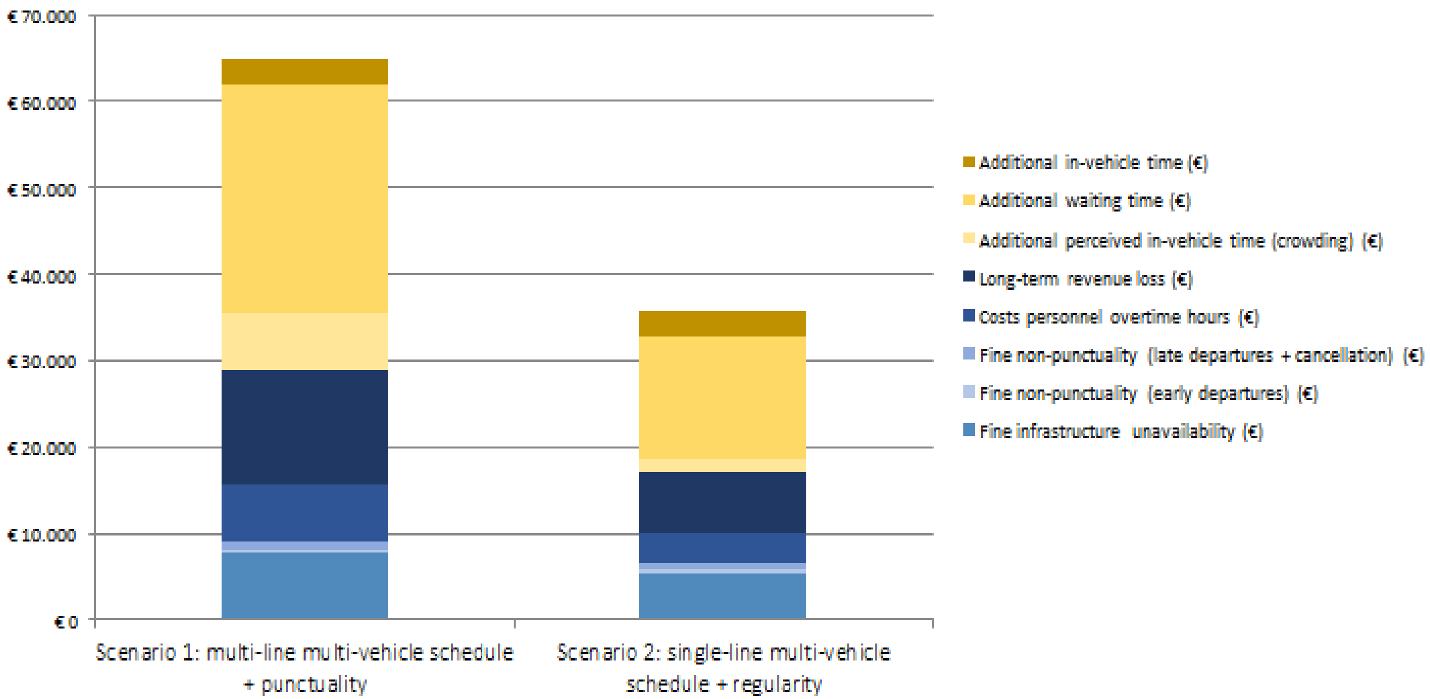
Results: costs per disruption

- Monetised costs per disruption (€):
  - Scenario 1: €29k (operator) + €36k (pax) = €65k (€1.1M yearly)
  - Scenario 2: €17k (operator) + €19k (pax) = €36k (€0.6M yearly)
  - Total disruption costs decrease by 45% in scenario 2



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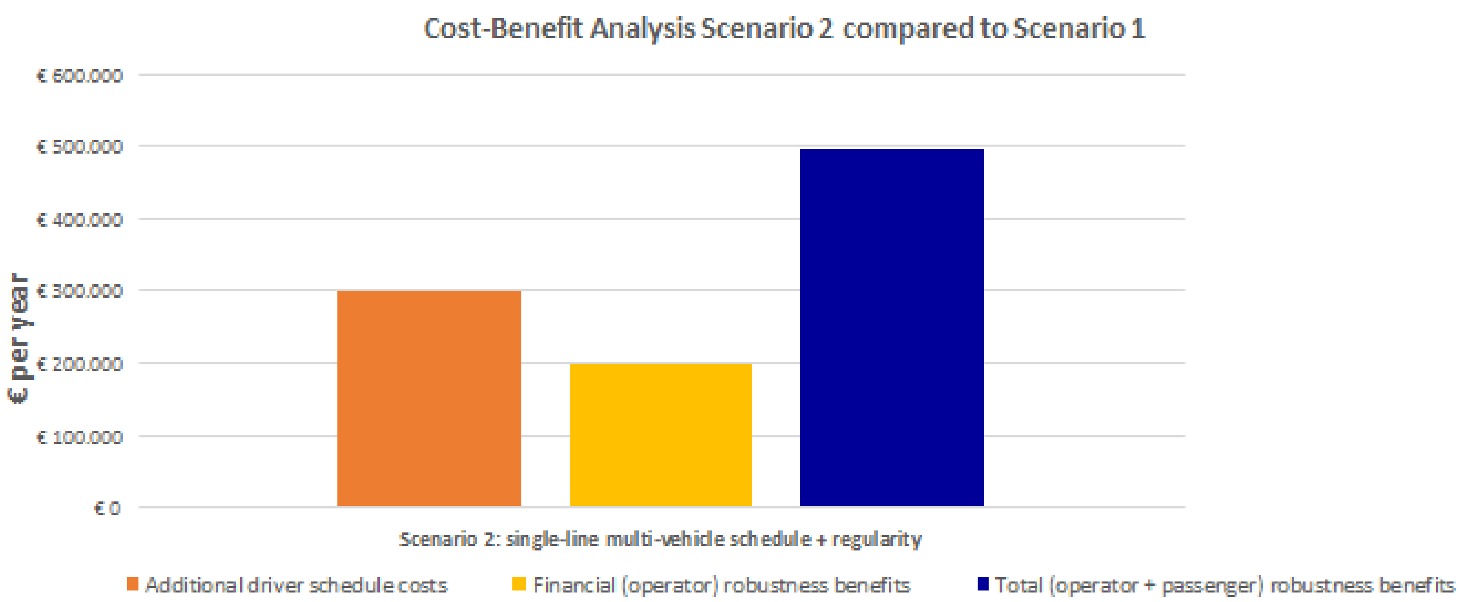
Results: cost-benefit analysis

- Monetised trade-off between disruption costs and driver schedule costs:
  - o Implementation of single-line multi-vehicle schedule + regularity
  - o Driver schedule costs increase by €300k
  - o Operator costs during disruptions decrease by €200k
  - o Societal costs (operator + passenger) decrease by €500k



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Discussion and conclusions

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- Benefits of complex driver schedule are overestimated if increased disruption costs are not considered:
  - Initial cost reduction of €300k
  - However: €200k costs / revenue loss
  - However: €500k total societal costs
- Role PT authority to bridge gap financial vs. societal costs?
- Further research (based on sensitivity analysis) :
  - More detailed study to service recovery time reduction
  - More detailed study to long-term demand elasticity value

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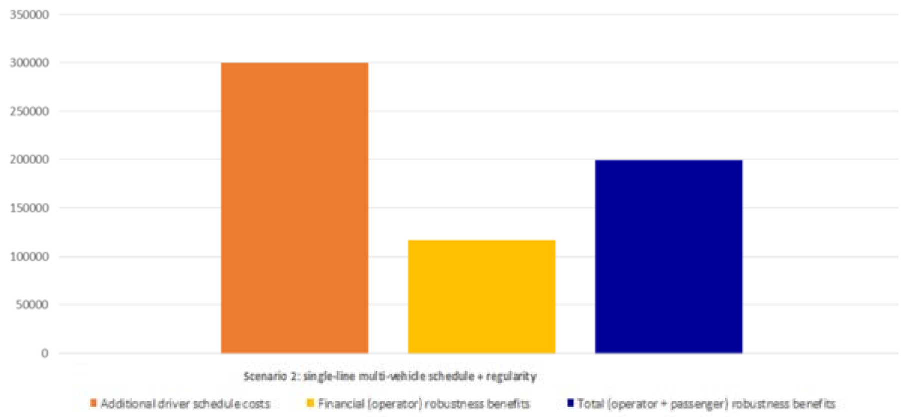
Results: sensitivity analysis

- Results sensitive to reduction service recovery time (50%)
  - Value of 30% (-40%) reduces operator benefits scenario 2 by €100k



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Results: sensitivity analysis

- Limited sensitivity to demand elasticity parameter (-0.5)
  - o Value -0.3 (-40%) reduces operator benefits scenario 2 by €50k