Supplementary material for Sousa et al., "Multiobjective model for optimizing railway infrastructure asset renewal", *Engineering Optimization*, 2018.

Appendix A

Table A1. Literature review on railway M&R actions.

Article	Main topic	One-line summary	Financial aspects/objectives	Operational aspects/objectives and other characteristics	Model type	Solution method
Sousa et al. (this work)	R actions optimization	Multiobjective model for scheduling renewal actions, considering financial aspects and work priorities	Min costs Investment leveling	Min priority-pondered postponements Train delays constraints	MILP	Exact
Zhao et al., 2009	R actions optimization	Model for planning renewal actions of multiple track components, from a cost-benefit perspective	Min costs Cost-benefit analysis	Considers savings from synchronizing renewals	MIP	Heuristic (genetic)
Li and Roberti, 2017	Construction projects optimization	Model for scheduling construction works considering different track possession types	Min costs	Operational constraints Renewals can be considered a type of project	MILP	Exact
Peralta et al., 2018	M&R actions optimization	Biobjective model for planning tamping & renewal operations, under safety and resource constraints	Min costs	Min train delays	Non-linear IP	Heuristic (NSGA II, AMOSA)
Lee et al., 2018	M&R actions optimization	Biobjective model for planning tamping & renewal operations, under quality index constraints	Min costs	Min nr. of tamping operations Quality index constraints	MIP	Heuristic (NSGA II)
Dao et al., 2018	M&R actions optimization	Model for planning M&R actions on multiple track components, considering limited possession times	Min life cycle costs (LCC)	Possession time constraints Possession costs monetized	MILP	Exact
Pargar et al., 2017	M&R actions optimization	Model for planning M&R actions by grouping interventions on multiple system components	Min costs	System downtimes monetized General model; can be adapted for railway M&R actions	MILP	Exact
Caetano and Teixeira, 2016	M&R actions optimization	Model for planning M&R actions on multiple track components, including discounts from reusing track components from renewed railway lines	Min LCC Budget constraints	Min track unavailability; monetized into LCC	MILP	Exact
Caetano and Teixeira, 2015	M&R actions optimization	Model for planning M&R actions on multiple track components, with discount factors from synchronizing renewals	Min LCC Budget constraints	Linear extension of Zhao et al. (2009) with inclusion of maintenance aspects	MILP	Exact

Article	Main topic	One-line summary	Financial aspects/objectives	Operational aspects/objectives and other characteristics	Model type	Solution method
Caetano and Teixeira, 2013	M&R actions optimization	Biobjective model for planning M&R actions on multiple track components	Min LCC Budget constraints	Min track unavailability	Multiobjective optimization	Heuristic (NSGA II)
Chu and Chen, 2012	M&R actions optimization	Threshold-based two-level model for planning general maintenance actions in a general infrastructure network	Budget constraints	Opt condition index Includes user responses in the lower-level problem General model; can be adapted for railway M&R actions	Two-level hybrid dynamic	Heuristic (tabu search)
Irfan et al., 2012	M&R actions optimization	Model for finding the best M&R action on a cost-effectiveness basis	Max benefit/cost ratio Budget constraints	Road pavement model; can be adapted for railway M&R	Non-linear MIP	Outer approximation Branch-and-bound
Andrade and Teixeira, 2011	M&R actions optimization	Biobjective model for planning M&R actions, based on track geometry	Min LCC	Min train delays Operational constraints (non-linear)	Non-linear MIP	Heuristic (simul. annealing)
Moghaddam and Usher (2011)	M&R actions optimization	Biobjective model for planning M&R actions on multiple component systems	Min costs	Max system reliability Allows for "do nothing" actions	Non-linear MIP	Heuristic (genetic, simul. annealing)
Yoo and Garcia-Diaz, 2008	M&R actions optimization	Model for finding the best M&R action with precedence-feasibility constraints	budget constraints	Max effectiveness of M&R actions Road pavement model; can be adapted for railway M&R	Binary optimization RCLPP formulation	Hybrid (dynamic program., branch-and-bound)
Gaudry et al., 2016	M&R actions and period optimization	Model for finding an optimal M&R policy and renewal period	Max profits	Rail traffic and service quality aspects accounted for	Dynamic programming	Pontryagin's method Numerical simulations
Zhang and Gao, 2012	M actions period optimization	Determines the optimal maintenance period considering three maintenance policies	Min LCC	Optimal period generates min LCC General model; can be adapted for railway M&R actions	Custom model	Custom algorithm
Pour et al., 2018	M actions optimization	Model for crew scheduling of railway signaling preventive maintenance		Min working days Min crew task gaps Max tasks completed	MILP	Exact Hybrid Weighted-sum
Xie et al., 2018	M actions optimization	Model for scheduling and routing maintenance operations, under variable productivities and operational constraints	Min costs	Operational constraints Constraint violations monetized	MILP VRP formulation	Exact (benchmark) Specialized heuristic
Consilvio et al., 2018	M actions optimization	Risk-based model for scheduling preventive maintenance		Min postponements Min distances travelled Min level repair assignments Works priorities	MILP	Exact (benchmark) Two-step heuristic Weighted-sum
Khouzani et al., 2017	M actions optimization	Model for scheduling tamping operations, based on a geometrical index	Budget constraints	Min degradation index Degradation index constraints	Binary optimization	Heuristic (genetic)
Wen et al., 2016	M actions optimization	Model for scheduling tamping operations	Min costs	Extension of Vale et al. (2012)	MILP	Exact
Baldi et al., 2016	M actions optimization	Model for obtaining optimized adaptive maintenance plans under uncertainty and considering risk	Min costs	Two scheduling horizons considered (short-term and rolling) lead to deterministic/stochastic scheduling problems respectively.	MILP	Exact (benchmark) Three specialized heuristics

| Article	Main topic	One-line summary	Financial aspects/objectives	Operational aspects/objectives and other characteristics	Model type	Solution method
Gustavsson, 2015	M actions optimization	Model for scheduling tamping operations, considering non-linear degradation	Min costs	Extension of Vale et al. (2012)	MILP	Exact
Peng and Ouyang, 2014	M actions optimization	Model for scheduling and routing maintenance operations with job clustering, considering team flow and under operational constraints	Min costs	Operational constraints (6 types) Extension of Peng and Ouyang (2012)	MILP	Exact Divide-and-conquer three-stage heuristic
Peng and Ouyang, 2012	M actions optimization	Model for scheduling and routing maintenance operations, considering team flow and under operational constraints derived from industry practice	Min costs	Operational constraints (8 types) Extension of Peng et al. (2011)	MILP	Exact Divide-and-conquer four-stage heuristic
Vale et al., 2012	M actions optimization	Model for scheduling tamping operations		Min nr. of tamping operations	MILP	Exact
Peng et al., 2011	M actions optimization	Model for scheduling and routing maintenance operations with limited availability of repair teams, under hard and soft operational constraints	Min costs	Min impacts on circulation Operational constraints Soft constraint violations monetized	MILP	Exact Project clustering heuristic
Budai et al., 2006	M actions optimization	Model for combined planning of routine and preventive maintenance actions	Min costs	Addresses two types of maintenance actions	MILP	Exact (benchmark) Four specialized heuristics
Higgins, 1998	M actions optimization	Model for planning current maintenance operations, considering repair team assignments, interference delays and priorities	Budget constraints	Min expected delays Min prioritized task end-time	Non-linear IP	Heuristic (tabu search) Weighted-sum
Montesinos-Valera et al., 2017	M&R actions evaluation	Multiattribute M&R projects prioritization		Ranks projects by priority 28 project performance criteria; grouped into 11 clusters	Multicriteria decision analysis	Analytic network process
Zhang et al., 2017	M&R actions evaluation	Petri net representation of M&R actions	Cost analysis	Tool for cost analysis	Petri networks	Monte-Carlo simulations
Prescott and Andrews, 2015	M&R actions evaluation	Markov model to evaluate railway performance response to M&R actions	Cost analysis	Performance, cost and risk analysis	Markov model	Numerical integration (4th order Runge-Kutta)
Guler, 2012	M&R actions decision support system	GIS and condition-based decision support system for M&R actions	budget constraints	Satisfaction of operational levels and staff constraints Software tool	Expert system	If-then rules
Odolinski and Wheat, 2018	M&R actions financial forecast	Statistical dynamic model for estimating M&R costs	Econometric analysis Cost elasticity estim.	Model calibration using real, historic data Forecast and policy analysis	Panel vector autoregressive	
Grimes and Barkan, 2006	M&R actions auditing	Comparison of effectiveness of M&R strategies using historic financial data	Min LCC	In practice, renewal actions are often more cost-effective than undertaking multiple maintenance actions	Audit methodology	

Appendix B
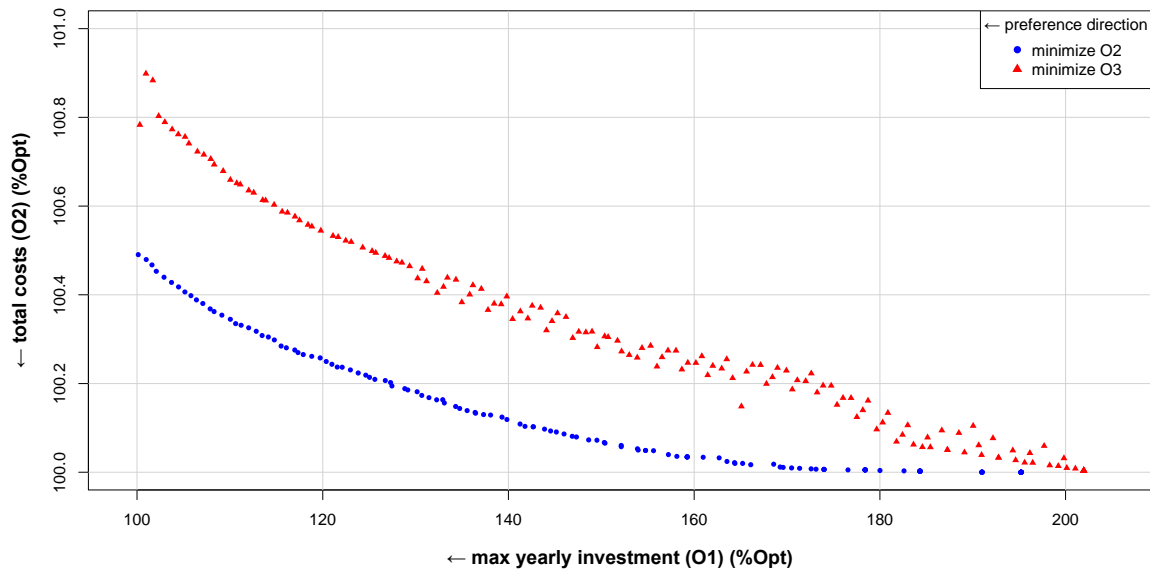
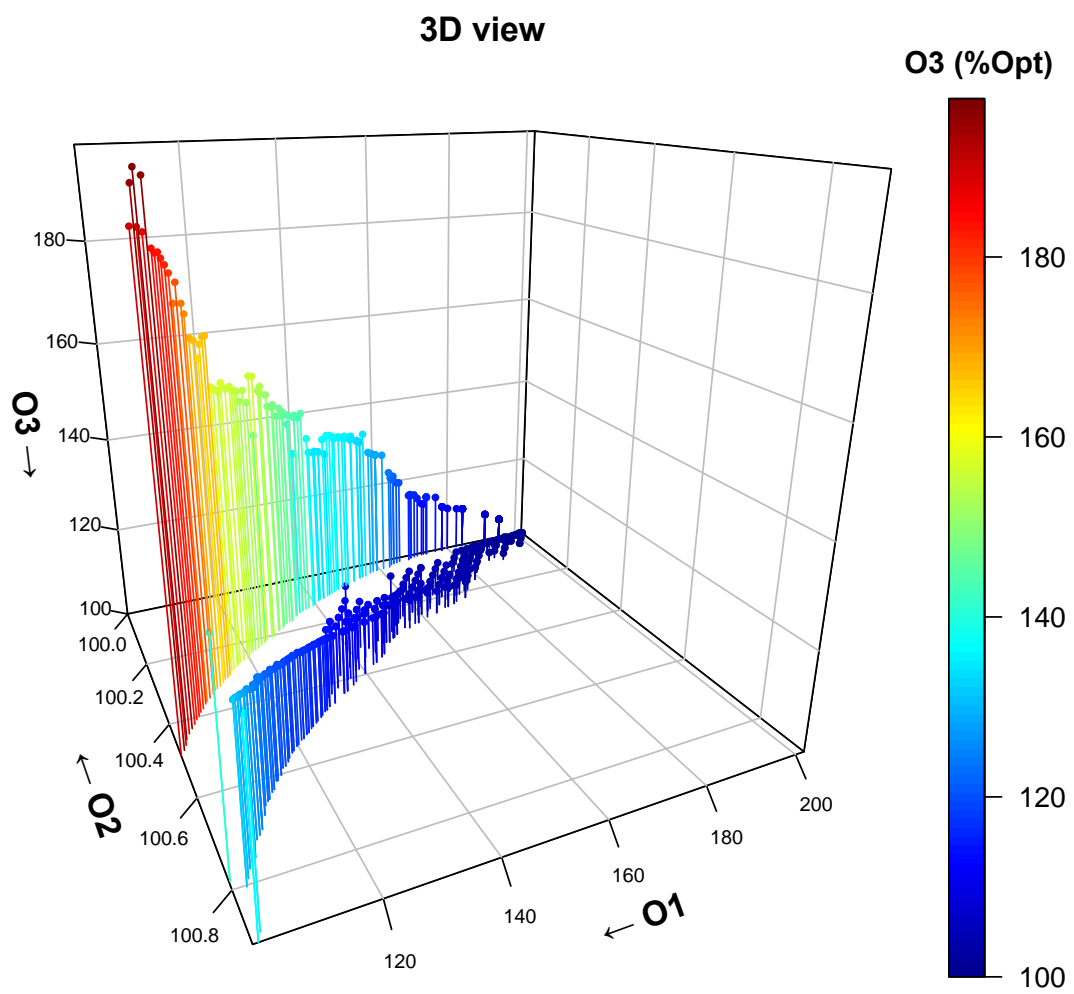Figure B1. Non-dominated solutions minimizing O2 and O3 in O1/O2 *xy* plot.

Figure B2. Non-dominated solutions minimizing O2 and O3 in 3D plot.