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Expert Competitive Traffic Light Optimization with Evolutionary Algorithms

Human Competitive Awards @ GECCO
July, 15th 2019, Prague

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Context

Cost of congestion in the US alone in 2017: 305 billion dollars! (source INRIX, 2018)

Vehicle related pollution causes respiratory conditions, cancer, birth defects, clinical depression
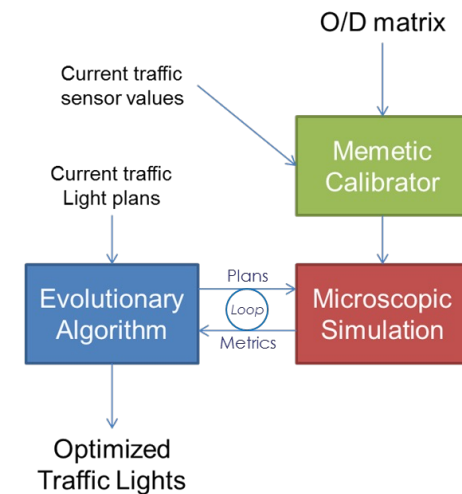
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Context

▍Traffic studies are extremely time consuming & expensive, agility & sustainability needed

▍A Thales business unit sells monitoring & control system for urban traffic

▍They can act on traffic and have experts but these <u>experts need help</u>: too many parameters, too many objectives, too many difficult decisions

▍Our answer: multi-objective evolutionary computation + calibrated microscopic simulation (SUMO)

▍Optimizes traffic lights on demand, on the fly reducing:

> Traffic jams (waiting time, # of processed vehicles, timeloss, etc.)

> Pollutant emissions: CO, CO2, NOx, HC, PMx

> Noise

> Fuel Consumption

▍Human-Competitive Baseline: existing, human engineered, traffic light plans

O/D matrix

Current traffic sensor values

Memetic Calibrator

Current traffic Light plans

Plans

Loop

Evolutionary Algorithm

Metrics

Microscopic Simulation

Optimized Traffic Lights

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Human-Competitive Criteria A&D: Patentability and Publishability

2 Patents in progress, both on ways to automatically produce traffic data objects of interest with supporting human-competitive experimental evidence:

> <u>Title</u>: Decision Tree Optimization for Urban Traffic Regulation, <u>Targeted Countries</u>: France & the rest of Europe

>> <u>Status</u>: Validated by internal Thales Intellectual Property Protection jury, French patent office filing targeted for summer 2019

> <u>Title</u>: Algorithmic Processing Chain for Urban Traffic Macro-Regulation, <u>Targeted Countries</u>: France & the rest of Europe

>> <u>Status</u>: Validated by internal Thales Intellectual Property Protection jury, French patent office filing targeted for summer 2019

Our reference paper was published in the Traffic Science community

> VEHITS: double blind peer-reviewed International Conference on Vehicle Technology and Intelligent Traffic Systems, Heraklion, Greece, May 3-5 2019, no direct link to Artificial Intelligence or Optimization

> Our contribution is unique in the state-of-the art: no other study is both as efficient and comprehensive (real-world data + classification + rigorous calibration + multi-objective + statistical validation + adaptive traffic lights) and none offers direct, fully documented, same conditions expert vs. algorithm comparison

> Short-listed for inclusion, as a 25 pages extended version in a Springer book due summer 2019

> What they are interested in is the result and its traits, not the producing algorithm

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Criteria A&D: Reverse Engineering on the Result Yields Valuable Insight

An interesting byproduct of optimization: analyzing building blocks of good solutions

1 example ([N/S TL E/W]):

> Initial plan: [29 12 21]

> Optimized plan : [20 5 20]

Observations: phases 1 and 2 are under capacity, phase 3 is over capacity

1 key lesson:

> Green time loss reduction (on under capacity phases) is primarily important, more so than green time reinforcement (on over capacity phases)

Improves expert methodology!

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Criterion G: Undisputable Difficulty

▌ **Notorious urban planning problem, has been defeating decision-makers for decades**

▌ **Traffic Science is an academic field of its own with dedicated laboratories, conferences and journals, there's even a dedicated Traffic Signal Practitioners Symposium (Sept 2019, Nottingham, UK)**

▌ **Traffic studies are extremely costly (highly qualified staff needed for long durations)**

▌ **Evolving context and varying requirements**

▌ **(Very) strong underlying mathematical difficulty, maddening for the expert in charge:**

> Highly Multi-Modal

> Chaotic

> Epistatic

> Highly non-separable

▌ **Our systems successfully solves the problem and produces, on a carefully calibrated basis, statistically validated gains ranging from 15 to 35% on static plans in all objectives with respect to the human engineered baseline and up to 56% on adaptive plans**

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Criterion H: Genetic Algorithms versus Experts

- **Growing trend in AI: opposing experts and algorithms in fair, realistic conditions**

- **Strong media impact**

- **Very powerful and convincing way to prove value and build trust**

- **Our rationale: see if we can bring that power to the Intelligent Traffic Systems community**

AI defeats elite doctors in diagnosis competition

TECH NEWS

Monday, 2 Jul 2018
7:00 PM MYT

By **Wang Xiaodong**

Radiologist Zhang Junhai from Shanghai Huashan Hospital reads a medical image display during a competition with BioMind, an artificial intelligence system, in Beijing. — China Daily

UC Magazine

Retired United States Air Force Colonel Gene Lee, in a flight simulator, takes part in simulated air combat versus artificial intelligence technology developed by a team comprised of industry, U.S. Air Force and University of Cincinnati representatives.*

Beyond video games: New artificial intelligence beats tactical experts in combat simulation

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Criterion H: Experimental Setup

Comparison workshop happens in standard conditions (engineering office premises, with their own computer, closed doors, unlimited time)

Experts are asked to :

> Make their methodology explicit and write it up beforehand (separate preliminary step)

> Can use any (non AI) tool or heuristic they want

> Can make as many trials as they need

> Trace each of their steps and successive attempts with corresponding gain

Algorithm in run in parallel (hidden) on the exact same test zone on a standard laptop without parallel computing.

**The exercise stops when the experts give up and cannot do any better.**
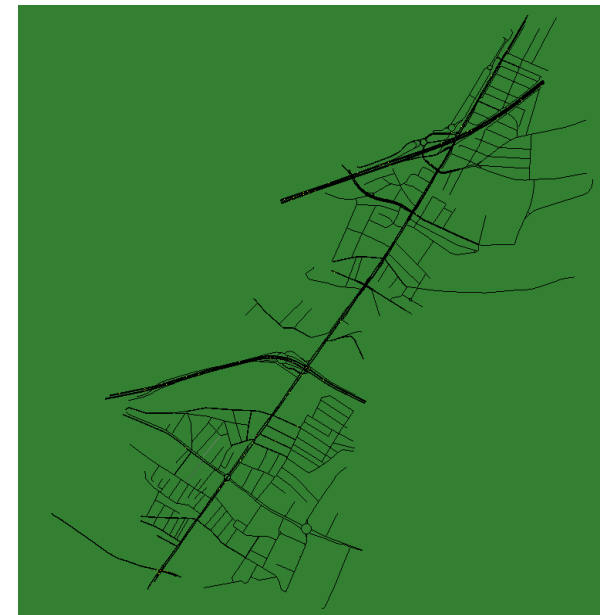
Test zone, Northern Suburbs of Paris

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Criterion H: Meet the Experts!

Three experts from CDVIA, a Paris-based traffic engineering office:

> Christian, M. Eng., 35+ years of experience, founder of the traffic engineering office, traffic regulation expert

> Benoit (right) M. Eng., 10 years of experience, project manager

> Aurélien (left), M. Eng, M. Sc, 5 years of experience, urban planning, regulation and simulation expert
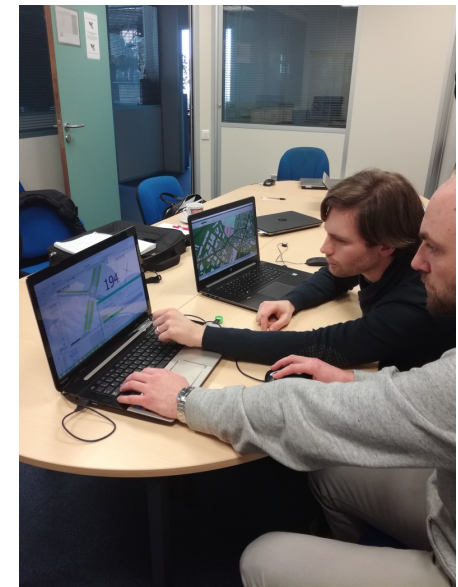
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Criterion H: Transcribed Expert Methodology

Rationale: formalizing, to some extent, a usually implicit, intuitive albeit experience-based process to produce a traceable reference to improve upon

Hypotheses: traffic conditions fixed, fixed plan structure, static plans, only modify green phases durations and temporal offsets
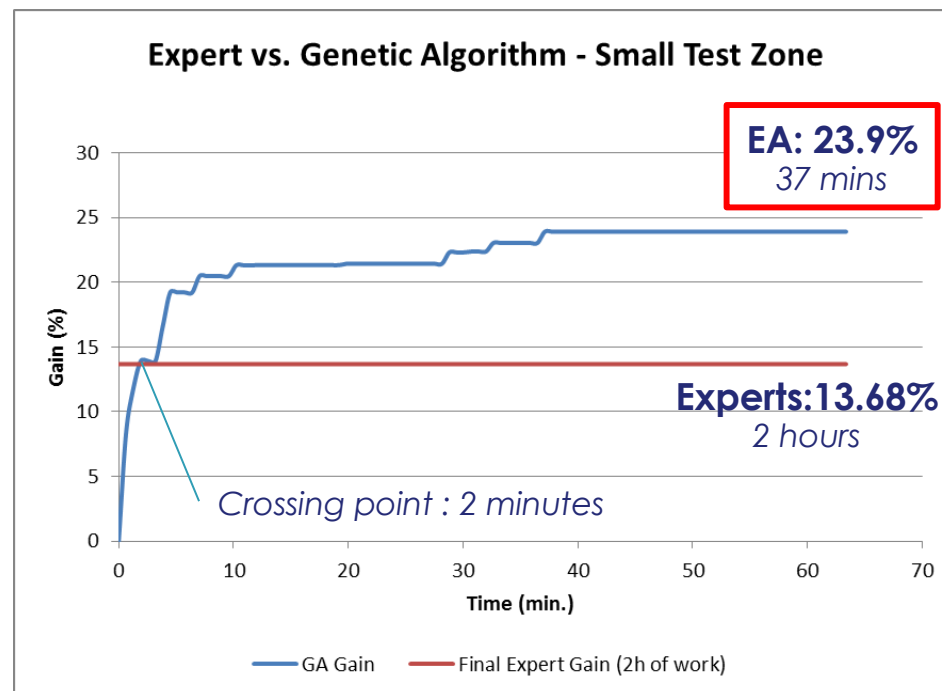
Methodology outline (further details in the paper):

1. Global static analysis (flows vs capacities)
2. Cycle length optimization
3. Green split optimization
4. Temporal offsets coordination (green waves)
5. Iterate as needed

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Criterion H: Results on the First Test Zone

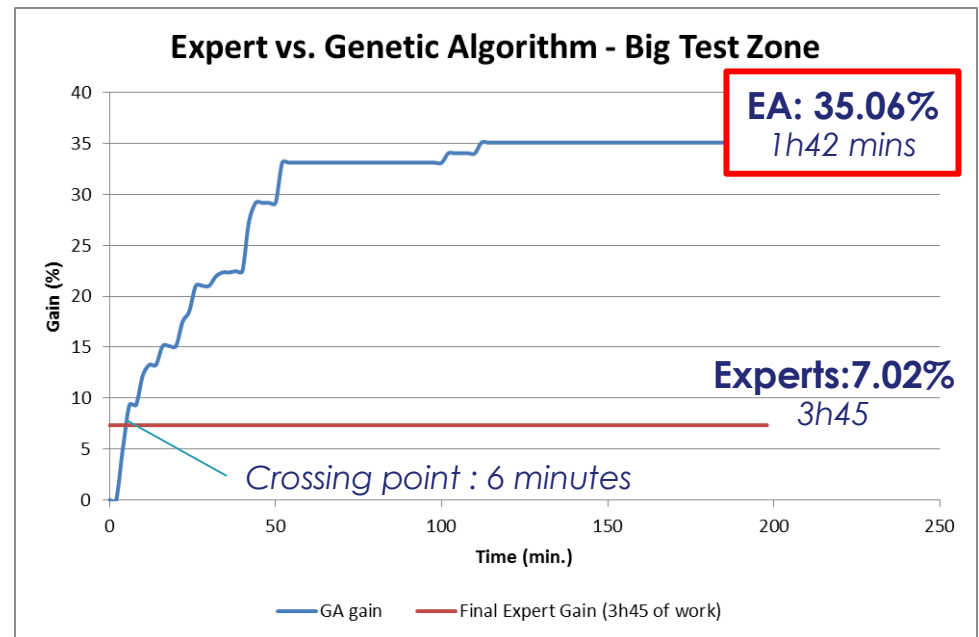## Expert optimization log

Step	Fitness	Gain (%)
Initial plan	112980	0
4s from phase N1 to phase N6	110228	2,43582935
6s from N1 to N6	116804	-3,38466985
5s N1 -> N6	110067	2,57833245
1s N4->N6 + 5s N1->N6	108296	4,14586653
Idem + 1s N4 ->N1	106523	5,71517083
Idem +2s N4 -> N1	108620	3,8590901
N* idem + 4s S6 -> S1	100766	10,810763
3s S6 -> S1	97552	13,6555143
5S S6 -> S1	100556	10,9966366
3s S1 -> S6	97651	13,5678881
1s S6 -> S1	97529	13,6758718

Expert vs. Genetic Algorithm - Small Test Zone

EA: 23.9%
37 mins

Experts:13.68%
2 hours

Crossing point : 2 minutes

— GA Gain   — Final Expert Gain (2h of work)

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Criterion H: Experts vs Algorithms on the Large Test Zone

Expert optimization log

Step	Fitness	Gain (%)
Initial plan	762000	0
Identifying 3 saturated junctions: A,B,C	N/A	
8s A1->A2	766000	-0,52493438
6s B1->B2	783000	-2,75590551
7s C1->C2	790000	-3,67454068
4s A1/B1/C1 -> A2/B2/C2	782000	-2,62467192
2s idem	775000	-1,70603675
minus 1s on all radial phases A2/B2/C2	782000	-2,62467192
minus 2s on all radial phases A2/B2/C2	750000	1,57480315
minus 3s on all radial phases A2/B2/C3	734000	3,67454068
minus 4s on all radial phases A2/B2/C4	**708000**	**7,08661417**
minus 5s on all radial phases A2/B2/C5	720000	5,51181102
minus 6s on all radial phases A2/B2/C6	742000	2,62467192
Other unsuccesful attemps on A and B	N/A	

Expert vs. Genetic Algorithm - Big Test Zone

EA: 35.06%
1h42 mins

Experts:7.02%
3h45

Crossing point : 6 minutes

Legend: GA gain — Final Expert Gain (3h45 of work)

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« Best » Statement

▌**Significant societal problem for both health and cost, billions of dollars at stake (Inrix Global Traffic Scorecard Study, 2018)**

▌**Difficult problem (highly unstable, numerous subtle combinatorial dependencies, treacherous search landscape)**

▌**Comprehensive approach (calibration particularly)**

▌**Several flavors of human-competitive results:**

> Optimized Traffic identification vs. Expert Heuristics

> Optimized Static Plans vs. Existing Baseline Plans

> Optimized Adaptive Plans vs. Expert Set Adaptive Plans

▌**Competition with actual experts in the exact same conditions:**

> Traced methodology & its application logs

> Published in the traffic science community

> **Actual experts agreed to testify that on a real-world case, they are largely outperformed by the Evolutionary Algorithm in both speed (x30) and final solution quality (x5)!**

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