Hours of service regulations in road freight transport: an optimization-based international assessment

Thibaut Vidal

utt université de technologie Troyes
Université de Montréal
CIRRELT Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport
CONSEIL REGIONAL CHAMPAGNE ARDENNE
Chaire de recherche industrielle du CRSNG en management logistique
NSERC Industrial Research Chair in Logistics Management

Seminar, Universidade Federal Fluminense,
March 15th, 2013

Context of this research

- Joint work with (scheduling aspect)

  Asvin GOEL, *Jacobs University*, Bremen, Germany

  and also: (routing aspect)

  Teodor Gabriel CRAINIC, *Université de Québec à Montréal, Canada*

  Michel GENDREAU, *Ecole Polytechnique, Montréal, Canada*

  Christian PRINS, *Université de Technologie de Troyes, France*

  (routing)

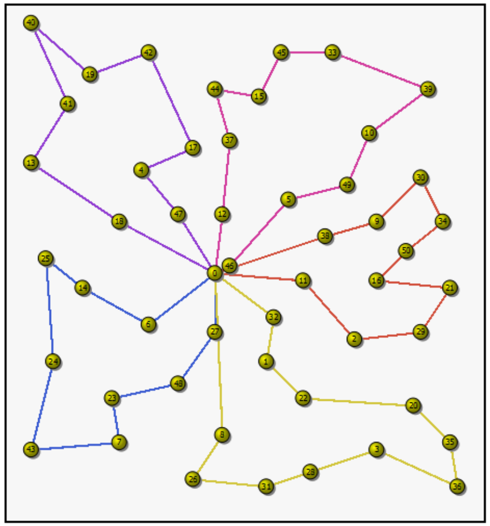
Presentation outline

- **Assessing the impact of hours of service (HOS) regulations on the travelling distance, duration and risk.**

- I) First discuss on **optimization methods** for vehicle routing.
- II) Some preliminary computational experiments.
- III) Have an efficient method for **generating high-quality itineraries in presence of different regulations**.
- IV) **Compare** these itineraries **and simulate risk**.

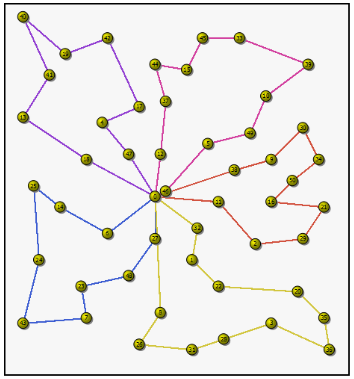
Vehicle routing problems

- **Capacitated vehicle routing problem:**
  - **INPUT :** *n* customers, with locations & demands. All-pair distances. Homogeneous fleet of *m* capacitated vehicles located at a central depot.
  - **OUTPUT** : Least-cost delivery routes (at most one route per vehicle) to service all customers.



- NP-Hard problem
- Exact resolution impracticable for most problem instances of interest (≥ 200 customers).
- "Scopus" facts : 2007-2011 = 1258 articles with the key *vehicle routing*.
- Massive research effort on heuristics.

Vehicle routing problems



- **Capacitated vehicle routing problem:**
  - Combinatorial optimization problem, for a problem with n=100 customers and a single vehicle, the number of possible solutions is:

n! = 93326215443944152681699238856266700490715968264381
62146859296389521759999322991560894146397615651828625369
7920827223758251185210916864000000000000000000000000 ≈ 10^{158}

  - Even with a grid of computers which…

Contains as many CPU as the estimated nb atoms in the Universe : $n_{CPU} = 10^{80}$

Does one operation per Planck time : $t_P = 5.39 \times 10^{-44}$ s

We need $T = 10^{158} \times 5.39 \times 10^{-44} / 10^{80} = 5.39 \times 10^{34}$ s to enumerate all solutions.

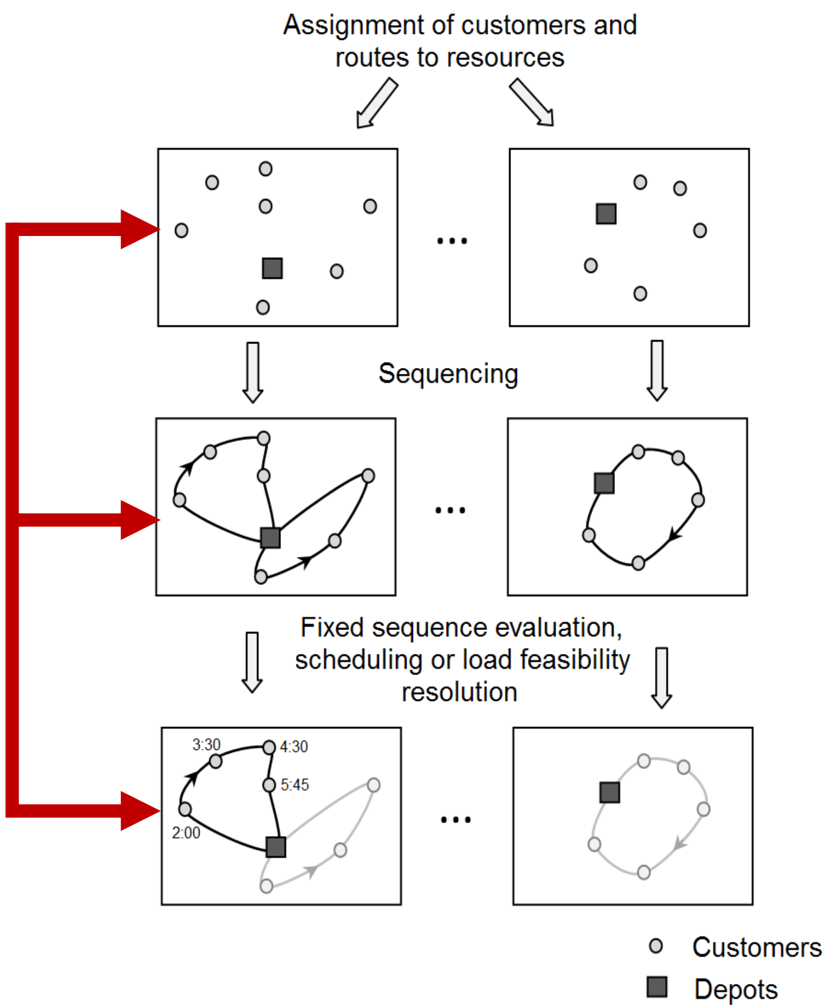
Compare this to the estimated age of Universe : 4.33×10^{17} s …

Vehicle routing problems

- **Vehicle routing "attributes" :** *Supplementary decisions, constraints and objectives which complement the problem formulations*
  - Modeling the specificities of application cases, customers requirements, network and vehicle specificities, operators abilities…
  - E.g. Time windows, Multiple periods, multiple depots, heterogeneous fleet, 2D-3D loading, time-dependent travel times…

- Multi-Attribute Vehicle Routing Problems (MAVRP)
  - Challenges : **VARIETY** of attributes
  - Challenges : **COMBINATION** of attributes
  - Plethora of attribute-specific methods in the literature, but no unified approach.

- **ASSIGNMENT**: assignment customers and routes to days and depots
  - **Take into account Periodic, Multi-Depot, Heterogeneous Fleet problems**
- **SEQUENCING:** create the sequence of visits to customers
- **ROUTE EVALUATION:** Evaluate each route generated during the search
  - **Time windows, Time-dep. travel time, Loading constraints, HOS regulations Lunch breaks, Load-Dependent costs…**

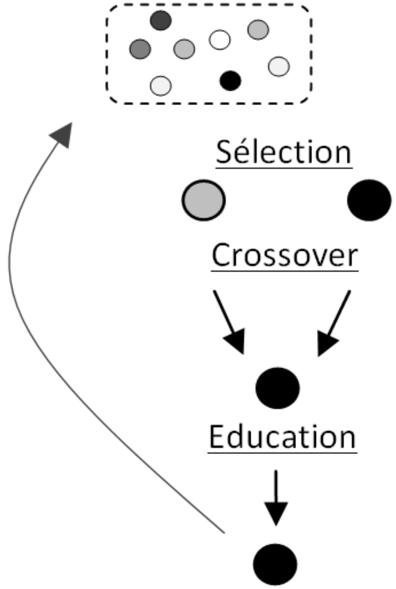


Unified genetic search with advanced diversity control

General HGA Methodology :

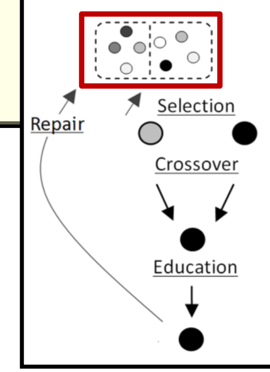
Evolve a population of solutions with genetic operators : selection, crossover and mutation.

Simulate a survival-of-the-fittest scheme to achieve high-quality solutions.

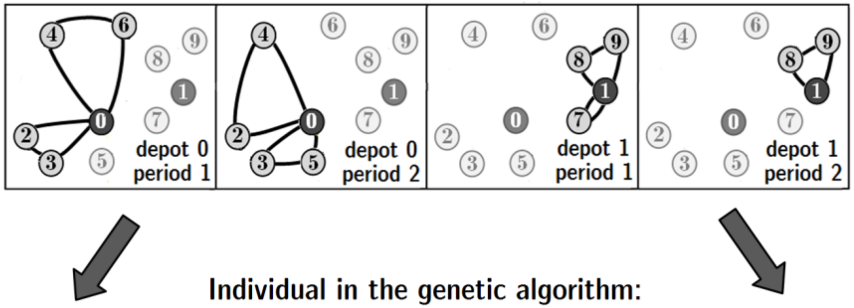


- Unified genetic search with Advanced Diversity Control (HGSADC):
  - Solution Representation *without trip delimiters* (Prins 2004)
  - High-performance local search-based *Education* procedure
  - Management of penalized infeasible solutions in two subpopulations
  - **Diversity & Cost objective for individuals evaluations**

Unified genetic search with advanced diversity control



- Solution Representation, *without trip delimiters,* (Prins 2004), one giant tour per (depot/day):



Individual in the genetic algorithm:

(P)

a) Pattern chromosome

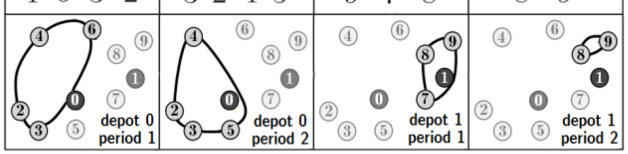
Cust i	2	3	4	5	6	7	8	9
Pat $\pi_i(P)$	{1,2}	{1,2}	{1,2}	{2}	{1}	{1}	{1,2}	{1,2}

b) Depot chromosome

Cust i	2	3	4	5	6	7	8	9
Dep $\delta_i(P)$	0	0	0	0	0	1	1	1

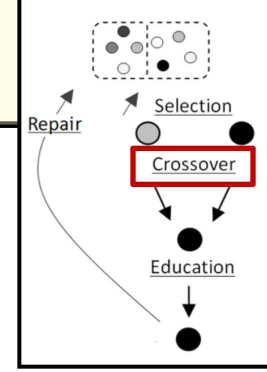
c) Giant tour chromosome

$\mathcal{V}_{01}(P)$	$\mathcal{V}_{02}(P)$	$\mathcal{V}_{11}(P)$	$\mathcal{V}_{12}(P)$
4 6 3 2	3 2 4 5	9 7 8	8 9

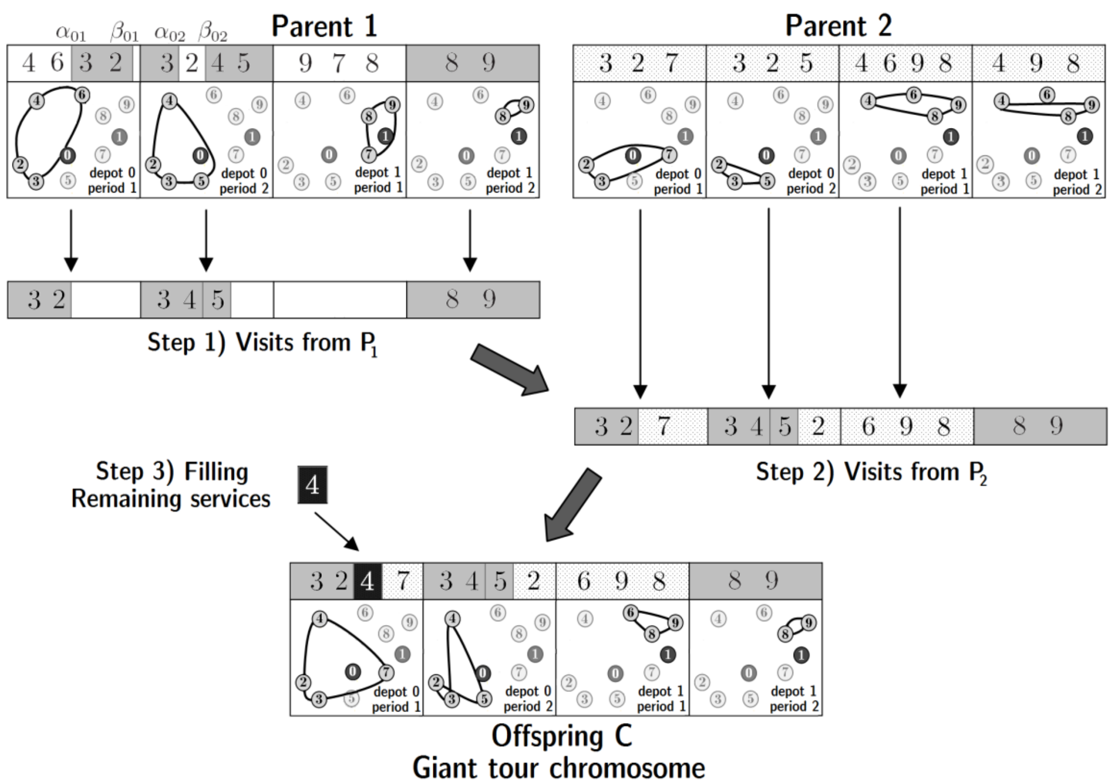


- A polynomial "Split" algorithm based on a shortest path can be used to obtain the trip delimiters.

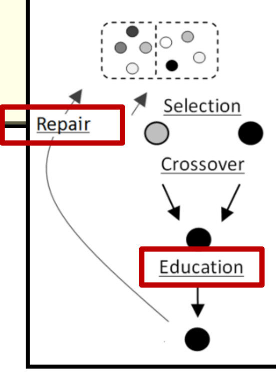
Unified genetic search with advanced diversity control



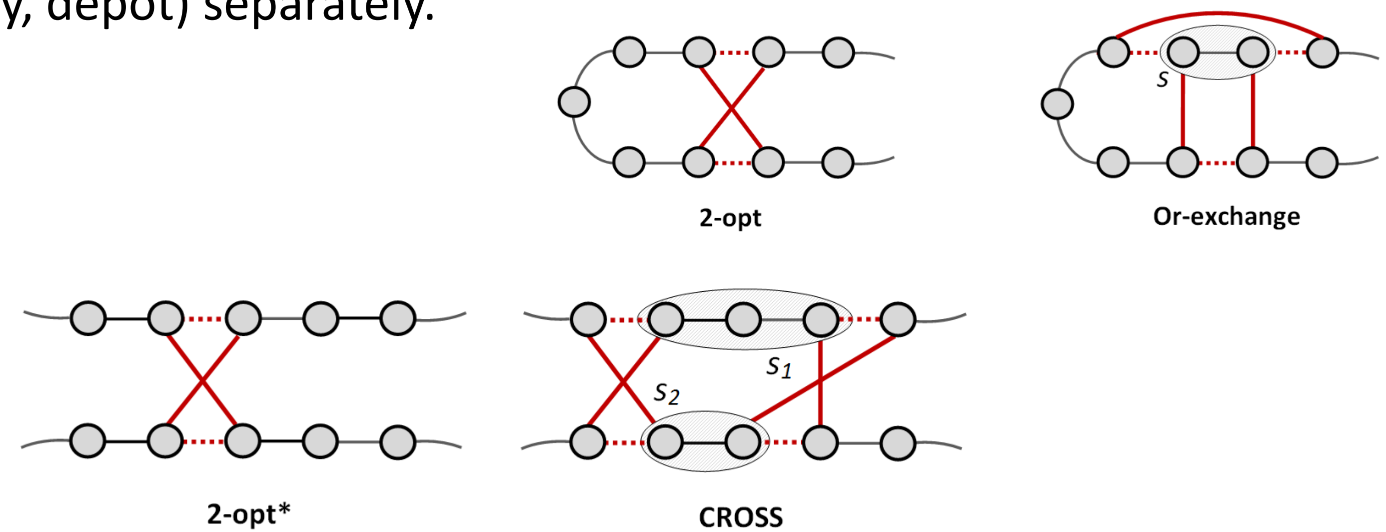
- Selection by binary tournament.
- New periodic crossover with insertions : inherits customer-to-day assignments and subsequences from the two parents.



Unified genetic search with advanced diversity control

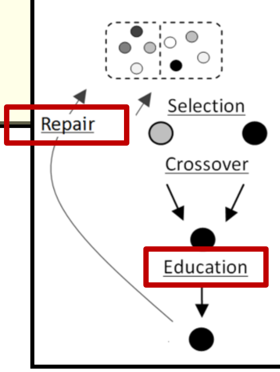


- **Education replaces mutation**
  - Two-level local search:
    - Route-improvement (RI) : insert, swap, 2-opt, 2-opt* for each (day, depot) separately.



    - Pattern-improvement (PI) : changing customer-to-days assignments.
    - Called in Sequence PI-RI-PI

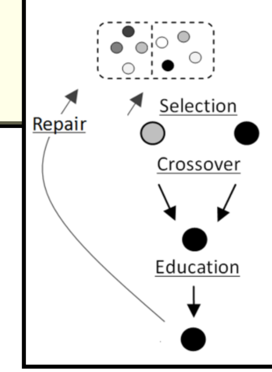
Unified genetic search with advanced diversity control



- Speed-up techniques and memories
  - Granular search (Toth and Vigo 2003): Testing only moves in RI involving correlated nodes (X% close in terms of distance)
  - Memories for moves and for insertion costs in any route.

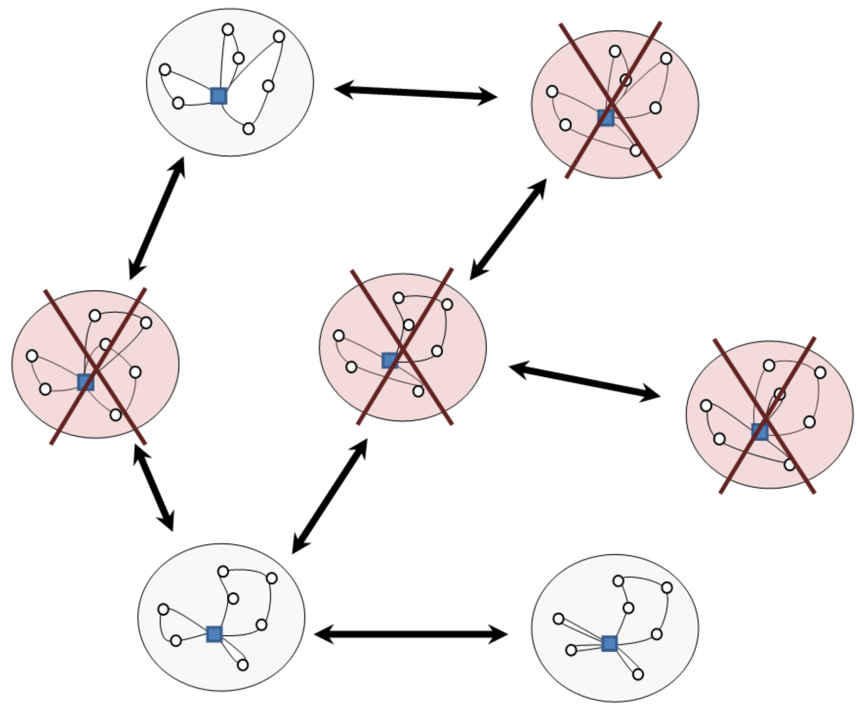
- **Repair** = Increase penalties and use education

Unified genetic search with advanced diversity control



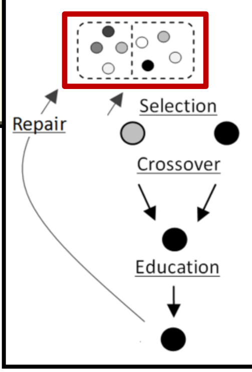
- The effect of route-constraints relaxations (load and duration) during local search…

- Helps transitioning between structurally different feasible solutions:



- Adaptation of penalty coefficients.

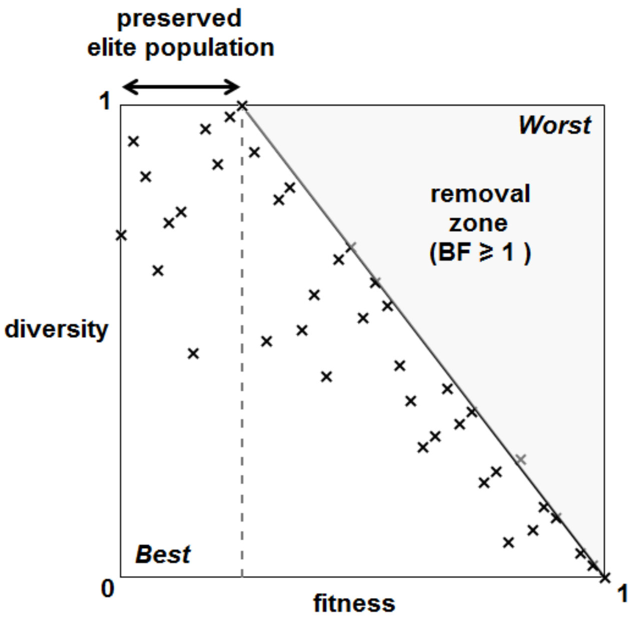
Unified genetic search with advanced diversity control



- **Biased Fitness** is a tradeoff between ranks in terms of **penalized cost** *fit(I)*, and **contribution to the diversity** *dc(I)*, measured as a distance to others individuals.

$$BF(I) = fit(I) + \left(1 - \frac{nbElit}{nbIndiv - 1}\right) \times dc(I)$$

- Used during selection of the parents
  - Balancing strength with innovation during reproduction, and thus favoring exploration of the search space.
- and during selection of survivors:
  - Removing the individual *I* with worst *BF(I)* also guarantees some elitism in terms of solution quality.



Computational Experiments on VRP instances

- Extensive computational experiments on 26 structurally different VRP variants and 39 sets of benchmark instances.
  - A total of 1008 problem instances.

- Comparing UHGS with the best problem-tailored method for each benchmark and problem. 10 runs on each problem.

- In the following, we indicate for each method
  - % Gap to the best known solution (BKS) of an average run (out of 10 for UHGS).
  - % Gap to the BKS of a best run (out of 10 for UHGS).
  - Computational effort (total work time) for an average run
  - Type of processor used.

Computational Experiments on VRP instances

Variant	Bench.	n	Obj.	State-of-the-art methods Author	Avg.%	Best%	T(min)	CPU
CVRP	CMT79	[50,199]	C	GG11:	—	+0.03%	8×2.38	8×Xe 2.3G
				MB07:	+0.03%	—	2.80	P-IV 2.8G
				UHGS*:	**+0.02%**	**+0.00%**	11.90	Opt 2.4G
CVRP	GWKC98	[200,483]	C	GG11:	—	+0.29%	8×5	8×Xe 2.3G
				NB09:	+0.27%	+0.16%	21.51	Opt 2.4G
				UHGS*:	**+0.15%**	**+0.02%**	71.41	Opt 2.4G
VRPB	GJ89	[25,200]	C	ZK12:	+0.38%	+0.00%	1.09	T5500 1.67G
				GA09:	+0.09%	+0.00%	1.13	Xe 2.4G
				UHGS:	**+0.01%**	**+0.00%**	0.99	Opt 2.4G
CCVRP	CMT79	[50,199]	C	NPW10:	+0.74%	+0.28%	5.20	Core2 2G
				RL12:	+0.37%	+0.07%	2.69	Core2 2G
				UHGS:	**+0.01%**	**-0.01%**	1.42	Opt 2.2G
CCVRP	GWKC98	[200,483]	C	NPW10:	+2.03%	+1.38%	94.13	Core2 2G
				RL12:	+0.34%	+0.07%	21.11	Core2 2G
				UHGS:	**-0.14%**	**-0.23%**	17.16	Opt 2.2G
VRPSDP	SN99	[50,199]	C	SDBOF10:	+0.16%	+0.00%	256×0.37	256×Xe 2.67G
				ZTK10:	—	+0.11%	—	T5500 1.66G
				UHGS:	**+0.01%**	**+0.00%**	2.79	Opt 2.4G
VRPSDP	MG06	[100,400]	C	SDBOF10:	+0.30%	+0.17%	256×3.11	256×Xe 2.67G
				UHGS:	+0.20%	+0.07%	12.00	Opt 2.4G
				S12 :	**+0.08%**	**+0.00%**	7.23	I7 2.93G

Computational Experiments on VRP instances

Variant	Bench.	n	Obj.	State-of-the-art methods				
				Author	Avg.%	Best%	T(min)	CPU
VFMP-F	G84	[20,100]	C	ISW09:	—	+0.07%	8.34	P-M 1.7G
				SPUO12:	+0.12%	+0.01%	0.15	I7 2.93G
				UHGS:	**+0.04%**	**+0.01%**	1.13	Opt 2.4G
VFMP-V	G84	[20,100]	C	ISW09:	—	+0.02%	8.85	P-M 1.7G
				SPUO12:	+0.17%	+0.00%	0.06	I7 2.93G
				UHGS:	**+0.03%**	**+0.00%**	0.85	Opt 2.4G
VFMP-FV	G84	[20,100]	C	P09:	—	+0.02%	0.39	P4M 1.8G
				UHGS:	+0.01%	+0.00%	0.99	Opt 2.4G
				SPUO12:	**+0.01%**	**+0.00%**	0.13	I7 2.93G
LDVRP	CMT79	[50,199]	C	XZKX12:	+0.48%	+0.00%	1.3	NC 1.6G
				UHGS:	**-0.28%**	**-0.33%**	2.34	Opt 2.2G
LDVRP	GWKC98	[200,483]	C	XZKX12:	+0.66%	+0.00%	3.3	NC 1.6G
				UHGS:	**-1.38%**	**-1.52%**	23.81	Opt 2.2G
PVRP	CGL97	[50,417]	C	HDH09:	+1.69%	+0.28%	3.09	P-IV 3.2G
				UHGS*:	+0.43%	+0.02%	6.78	Opt 2.4G
				CM12:	**+0.24%**	**+0.06%**	64×3.55	64×Xe 3G
MDVRP	CGL97	[50,288]	C	CM12:	+0.09%	+0.03%	64×3.28	64×Xe 3G
				S12:	+0.07%	+0.02%	11.81	I7 2.93G
				UHGS*:	**+0.08%**	**+0.00%**	5.17	Opt 2.4G
GVRP	B11	[16,262]	C	BER11:	+0.06%	—	0.01	Opt 2.4G
				MCR12:	+0.11%	—	0.34	Duo 1.83G
				UHGS:	**+0.00%**	**-0.01%**	1.53	Opt 2.4G

Computational Experiments on VRP instances

Variant	Bench.	n	Obj.	State-of-the-art methods Author	Avg.%	Best%	T(min)	CPU
OVRP	CMT79 &F94	[50,199]	F/C	RTBI10:	0%/+0.32%	—	9.54	P-IV 2.8G
				S12:	—/+0.16%	0%/+0.00%	2.39	I7 2.93G
				UHGS:	**0%/+0.11%**	**0%/+0.00%**	1.97	Opt 2.4G
OVRP	GWKC98	[200,480]	F/C	ZK10:	0%/+0.39%	0%/+0.21%	14.79	T5500 1.66G
				S12:	0%/+0.13%	0%/+0.00%	64.07	I7 2.93G
				UHGS:	**0%/-0.11%**	**0%/-0.19%**	16.82	Opt 2.4G
VRPTW	SD88	100	F/C	RTI09:	0%/+0.11%	0%/+0.04%	17.9	Opt 2.3G
				UHGS*:	0%/+0.04%	0%/+0.01%	2.68	Xe 2.93G
				NBD10:	**0%/+0.02%**	**0%/+0.00%**	5.0	Opt 2.4G
VRPTW	HG99	[200,1000]	F/C	RTI09b:	—	+0.16%/+3.36%	270	Opt 2.3G
				NBD10:	+0.20%/+0.42%	+0.10%/+0.27%	21,7	Opt 2.4G
				UHGS*:	**+0.18%/+0.11%**	**+0.08%/-0.10%**	141	Xe 2.93G
OVRPTW	SD88	100	F/C	RTI09a:	+0.89%/+0.42%	0%/+0.24%	10.0	P-IV 3.0G
				KTDHS12:	0%/+0.79%	0%/+0.18%	10.0	Xe 2.67G
				UHGS:	**+0.09%/-0.10%**	**0%/-0.10%**	5.27	Opt 2.2G
TDVRPTW	SD88	100	F/C	KTDHS12:	+2.25%	0%	10.0	Xe 2.67G
				UHGS:	**-3.31%**	**-3.68%**	21.94	Opt 2.2G
VFMPTW	LS99	100	D	BDHMG08:	—	+0.59%	10.15	Ath 2.6G
				RT10:	+0.22%	—	16.67	P-IV 3.4G
				UHGS:	**-0.15%**	**-0.24%**	4.58	Opt 2.2G
VFMPTW	LS99	100	C	BDHMG08:	—	+0.25%	3.55	Ath 2.6G
				BPDRT09:	—	+0.17%	0.06	Duo 2.4G
				UHGS:	-0.38%	-0.49%	4.82	Opt 2.2G

Computational Experiments on VRP instances

Variant	Bench.	n	Obj.	State-of-the-art methods Author	Avg.%	Best%	T(min)	CPU
PVRPTW	CL01	[48,288]	C	PR08:	—	+1.75%	—	Opt 2.2G
				CM12:	+1.10%	+0.76%	64×11.3	64×Xe 3G
				UHGS*:	**+0.63%**	**+0.22%**	32.7	Xe 2.93G
MDVRPTW	CL01	[48,288]	C	PBDH08:	—	+1.37%	147	P-IV 3.6G
				CM12:	+0.36%	+0.15%	64×6.57	64×Xe 3G
				UHGS*:	**+0.19%**	**+0.03%**	6.49	Xe 2.93G
SDVRPTW	CL01	[48,288]	C	B10:	+2.23%	—	2.94	Qd 2.67G
				CM12:	+0.62%	+0.36%	64×5.60	64×Xe 3G
				UHGS*:	**+0.36%**	**+0.10%**	5.48	Xe 2.93G
VRPSTW (type 1, α=100)	SD88	100	F/TW/C	F10:	0%	—	9.69	P-M 1.6G
				UHGS:	**-3.05%**	**-4.42%**	18.62	Opt 2.2G
VRPSTW (type 1, α=1)	SD88	100	C+TW	KTDHS12:	+0.62%	+0.00%	10.0	Xe 2.67G
				UHGS:	**-0.13%**	**-0.18%**	5.82	Opt 2.2G
VRPSTW (type 2, α=100)	SD88	100	F/TW/C	FEL07:	0%	—	5.98	P-II 600M
				UHGS:	**-13.91%**	**-13.91%**	41.16	Opt 2.2G
VRPSTW (type 2, α=1)	SD88	100	C+TW	**UHGS:**	**+0.26%**	**0%**	29.96	Opt 2.2G
MDPVRPTW	New	[48,288]	C	**UHGS:**	**+0.77%**	**0%**	16.89	Opt 2.2G
VRTDSP (E.U. rules)	G09	100	F/C	PDDR10:	0%/0%	0%/0%	88	Opt 2.3G
				UHGS*:	**-0.56%/-0.54%**	**-0.85%/-0.70%**	228	Xe 2.93G

Computational Experiments on VRP instances

- **Matching or outperforming the current best 180 problem-dedicated algorithms from the literature for 29 problems and 38 benchmark instance sets !!!**

- BKS has been found or improved on 954/1008 problems
- Strictly improved on 550/1008 problems.
- All known optimal solutions have been retrieved !!
- Run time of a few minutes for average-size instances (n = 200-300)
- Standard deviation below 0.1%

- **Suitable as an optimization method to generate routes for our HOS regulations assessment.**

Thank you for your attention !

- <u>For further reading, and follow-up works:</u>

- Goel, A., & Vidal, T. (2012). Hours of service regulations in road freight transport : an optimization-based international assessment. *Submitted to Transportation Science Revised. Tech Rep CIRRELT-2012-08.*
- Vidal, T., Crainic, T. G., Gendreau, M., Lahrichi, N., & Rei, W. (2012*).* A Hybrid Genetic Algorithm for Multi-Depot and Periodic Vehicle Routing Problems. *Operations Research*, 60(3), 611–624.
- Vidal, T., Crainic, T. G., Gendreau, M., & Prins, C. (2013). A hybrid genetic algorithm with adaptive diversity management for a large class of vehicle routing problems with time-windows. *Computers & Operations Research*, 40(1), 475–489.
- Vidal T., Crainic T.G., Gendreau M., Prins C. Heuristics for Multi-Attribute Vehicle Routing Problems: A Survey and Synthesis (2013). *European Journal of Operations Research, to appear.*
- Vidal, T., Crainic, T. G., Gendreau, M., & Prins, C. (2012). A Unifying View on Timing Problems and Algorithms. *Submitted to C&OR. Tech Rep CIRRELT-2011-43.*
- Vidal, T., Crainic, T. G., Gendreau, M., & Prins, C. (2012). A Unified Solution Framework for Multi-Attribute Vehicle Routing Problems. *Submitted to Operations Research. Tech Rep CIRRELT-2012-23.*
- Vidal, T., Crainic, T. G., Gendreau, M., & Prins, C. (2012). Implicit Depot Assignments and Rotations in Vehicle Routing Heuristics. *Submitted to EJOR. Tech Rep CIRRELT-2012-60.*

- **These papers + some others + slides can be found at** http://w1.cirrelt.ca/~vidalt/

Hours of Service Regulations in Road Transport

Fatigue

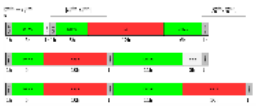
Truck driver fatigue is internationally recognised as a significant factor in 15-20% of all commercial road transport crashes

To improve road safety governments world wide are adopting stricter hours of service regulations for truck drivers

Some regulations introduce a "chain of responsibility" so that dispatchers can be made liable for unrealistic schedules

Truck Driver Scheduling

Problem:
Given a sequence of customer locations to be visited within given time windows, find a schedule complying with applicable hours of service regulations such that each customer is visited within the respective time window



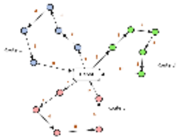
Solution Approach

Regulatory Impact Analysis

- We assume that carrier seeks to minimise total costs
- Optimise routes for different regulations using hybrid genetic search
- Analyse solutions regarding total costs and road safety
- Fatigue/Risk Index Calculator provided by Health and Safety Executive - UK (http://www.hse.gov.uk/research/rrhtm/rr446.htm)

Vehicle Routing

In many applications we must consider hours of service regulations when optimising vehicle routes



Hybrid Genetic Search

Computational Experiments

Asvin Goel, Thibaut Vidal

Seminar UFPB,
15 March 2013

Zaragoza Logistics Center
Universität Leipzig
LPZ E-Business
Université de Montréal
utt
CIRRELT
Conseil Régional Champagne Ardenne

Hours of Service Regulations in Road Transport

Fatigue

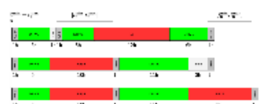
Truck driver fatigue is internationally recognised as a significant factor in 15-20% of all commercial road transport crashes

To improve road safety governments world wide are adopting stricter hours of service regulations for truck drivers

Some regulations introduce a "chain of responsibility" so that dispatchers can be made liable for unrealistic schedules

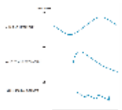
Truck Driver Scheduling

Problem:
Given a sequence of customer locations to be visited within given time windows, find a schedule complying with applicable hours of service regulations such that each customer is visited within the respective time window



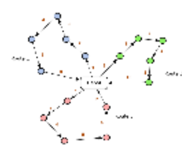
Regulatory Impact Analysis

- We assume that carrier seeks to minimise total costs
- Optimise routes for different regulations using hybrid genetic search
- Analyse solutions regarding total costs and road safety
- Fatigue/Risk Index Calculator provided by Health and Safety Executive - UK (http://www.hse.gov.uk/research/rrhtm/rr446.htm)



Vehicle Routing

In many applications we must consider hours of service regulations when optimising vehicle routes



Asvin Goel, Thibaut Vidal

Seminar UFPB,
15 March 2013

ZARAGOZA LOGISTICS CENTER · UNIVERSITAT LEIPZIG · LPZ E-BUSINESS · Université de Montréal · utt · CIRRELT · CONSEIL RÉGIONAL CHAMPAGNE ARDENNE

Asvin Goel, Thibaut Vidal

Seminar UFPB,
15 March 2013

ZARAGOZA LOGISTICS CENTER
UNIVERSITÄT LEIPZIG
LPZ E-BUSINESS applied telematics
Université de Montréal
utt université de technologie Troyes
CIRRELT
CONSEIL REGIONAL CHAMPAGNE ARDENNE

Fatigue

Truck driver fatigue is internationally recognised as a significant factor in 15-20% of all commercial road transport crashes

To improve road safety governments world wide are adopting stricter hours of service regulations for truck drivers

Some regulations introduce a "chain of responsibility" so that dispatchers can be made liable for unrealistic schedules

Hours of Service Regulations in Road Transport

Fatigue

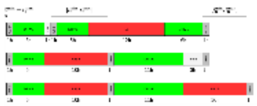
Truck driver fatigue is internationally recognised as a significant factor in 15-20% of all commercial road transport crashes

To improve road safety governments world wide are adopting stricter hours of service regulations for truck drivers

Some regulations introduce a "chain of responsibility" so that dispatchers can be made liable for unrealistic schedules

Truck Driver Scheduling

Problem:
Given a sequence of customer locations to be visited within given time windows, find a schedule complying with applicable hours of service regulations such that each customer is visited within the respective time window



Solution Approach

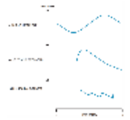
Asvin Goel, Thibaut Vidal

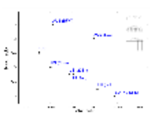
Seminar UFPB,
15 March 2013

ZARAGOZA LOGISTICS CENTER · UNIVERSITÄT LEIPZIG · LPZ E-BUSINESS · Université de Montréal · utt · CIRRELT · CONSEIL RÉGIONAL CHAMPAGNE ARDENNE

Regulatory Impact Analysis

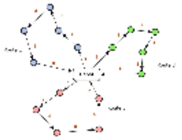
- We assume that carrier seeks to minimise total costs
- Optimise routes for different regulations using hybrid genetic search
- Analyse solutions regarding total costs and road safety
- Fatigue/Risk Index Calculator provided by Health and Safety Executive - UK (http://www.hse.gov.uk/research/rrhtm/rr446.htm)





Vehicle Routing

In many applications we must consider hours of service regulations when optimising vehicle routes



Hybrid Genetic Search

Computational Experiments

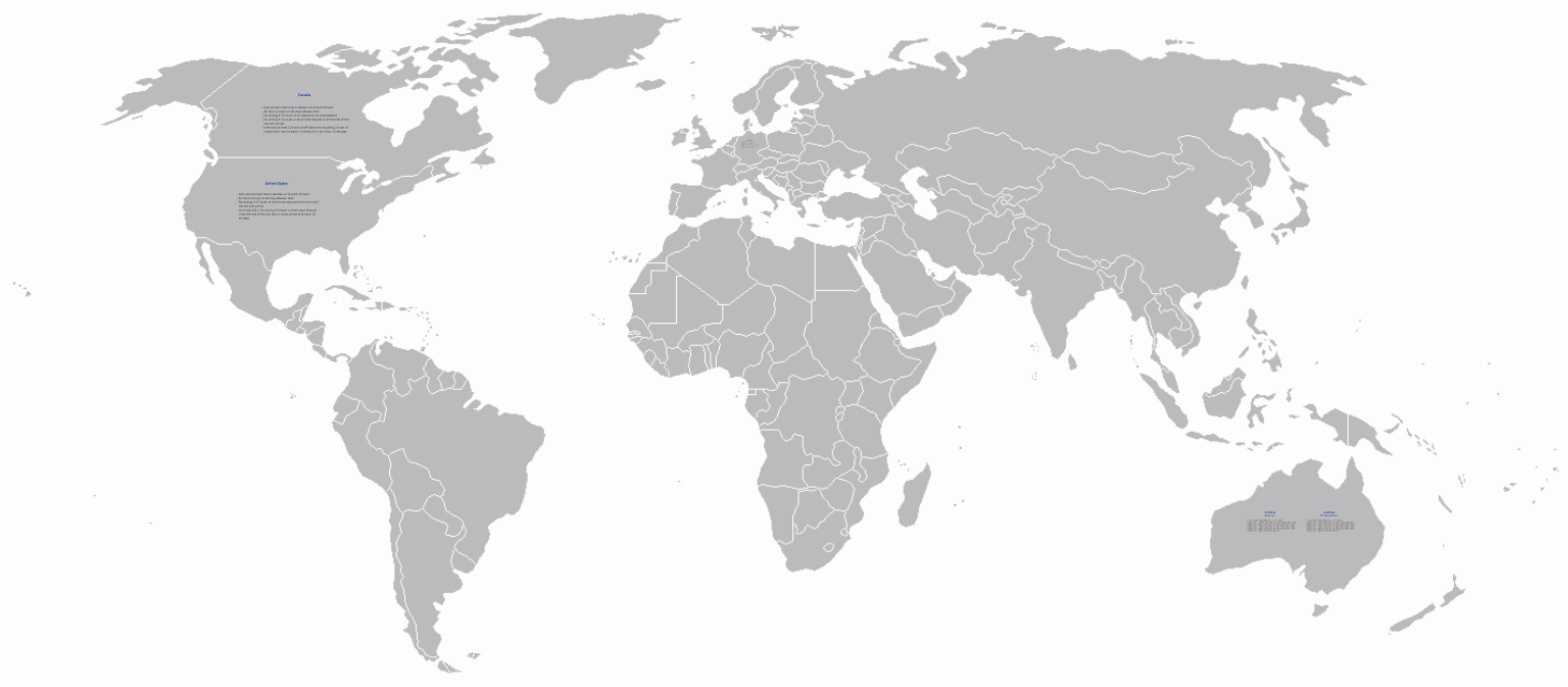

Canada
United States

United States

- Rest periods must have a duration of at least 10 hours
- At most 11 hours of driving between rests
- No driving if 14 hours or more have elapsed since the end of the last rest period
- From July 2013: No driving if 8 hours or more have elapsed since the end of the last rest or break period of at least 30 minutes

Canada

- Rest periods must have a duration of at least 8 hours
- At most 13 hours of driving between rests
- No driving if 14 hours of on-duty time are accumulated
- No driving if 16 hours or more have elapsed since the end of the last rest period
- Every day at least 10 hours of off-duty time including 2 hours of break which may be taken in blocks of no less than 30 minutes



Canada
United States

European Union

- Rest periods must have a duration of at least 11 hours
- At most 9 hours of driving between rests
- A break of 45 minutes must be taken after 4½ hours of driving
- Rest periods must be completed 24 hours after end of previous rest
- Breaks may be split in a first part of 15 minutes and a second part of 30 minutes
- Rests may be split in a first part of 3 hours and a second part of 9 hours
- Three times in a week a rest may be reduced to 9 hours
- Two times in a week driving between rests can be extended to 10 hours


Canada
United States

Australia

(Standard Hours)

- Rest periods must have a duration of at least 7 hours
- In any period of 5½ hours a driver must not work for more than 5¼ hours
- In any period of 8 hours a driver must not work for more than 7½ hours
- In any period of 11 hours a driver must not work for more than 10 hours
- In any period of 24 hours a driver must not work for more than 12 hours
- In any period of 24 hours a driver must have a rest

Australia

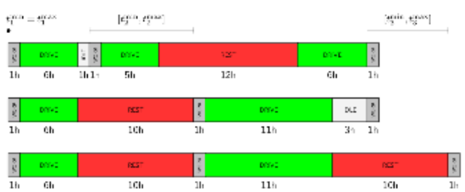
(Basic Fatigue Management)

- Rest periods must have a duration of at least 7 hours
- In any period of 6¼ hours a driver must not work for more than 6 hours
- In any period of 9 hours a driver must not work for more than 8½ hours
- In any period of 12 hours a driver must not work for more than 11 hours
- In any period of 24 hours a driver must not work for more than 14 hours
- In any period of 24 hours a driver must have a rest

Regulations in Road Transport

Truck Driver Scheduling

Problem:
Given a sequence of customer locations to be visited within given time windows, find a schedule complying with applicable hours of service regulations such that each customer is visited within the respective time window



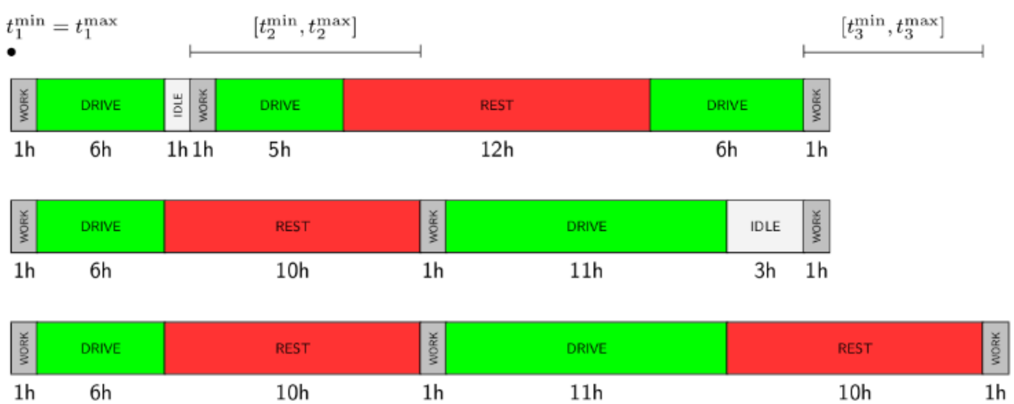
Vehicle Routing

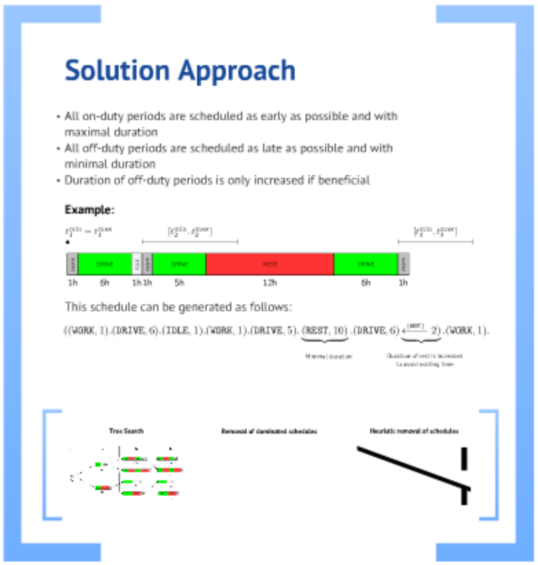
Asvin Goel, Thibaut Vidal

Seminar UFPB,
15 March 2013

Truck Driver Scheduling

Problem:
Given a sequence of customer locations to be visited within given time windows, find a schedule complying with applicable hours of service regulations such that each customer is visited within the respective time window



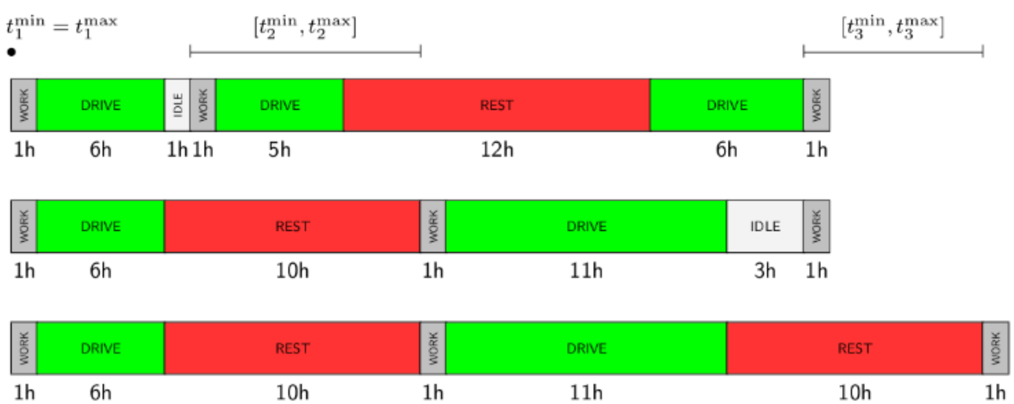


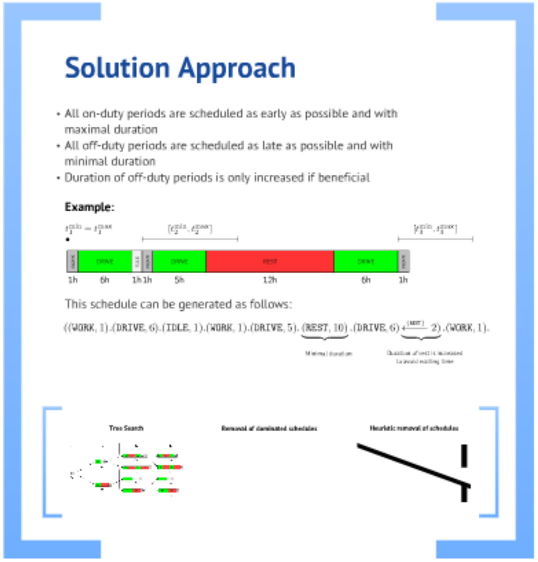
f service regulations such that each customer is visited within
he respective time window

Truck Driver Scheduling

Problem:

Given a sequence of customer locations to be visited within given time windows, find a schedule complying with applicable hours of service regulations such that each customer is visited within the respective time window





Solution Approach

- All on-duty periods are scheduled as early as possible and with maximal duration
- All off-duty periods are scheduled as late as possible and with minimal duration
- Duration of off-duty periods is only increased if beneficial

Example:

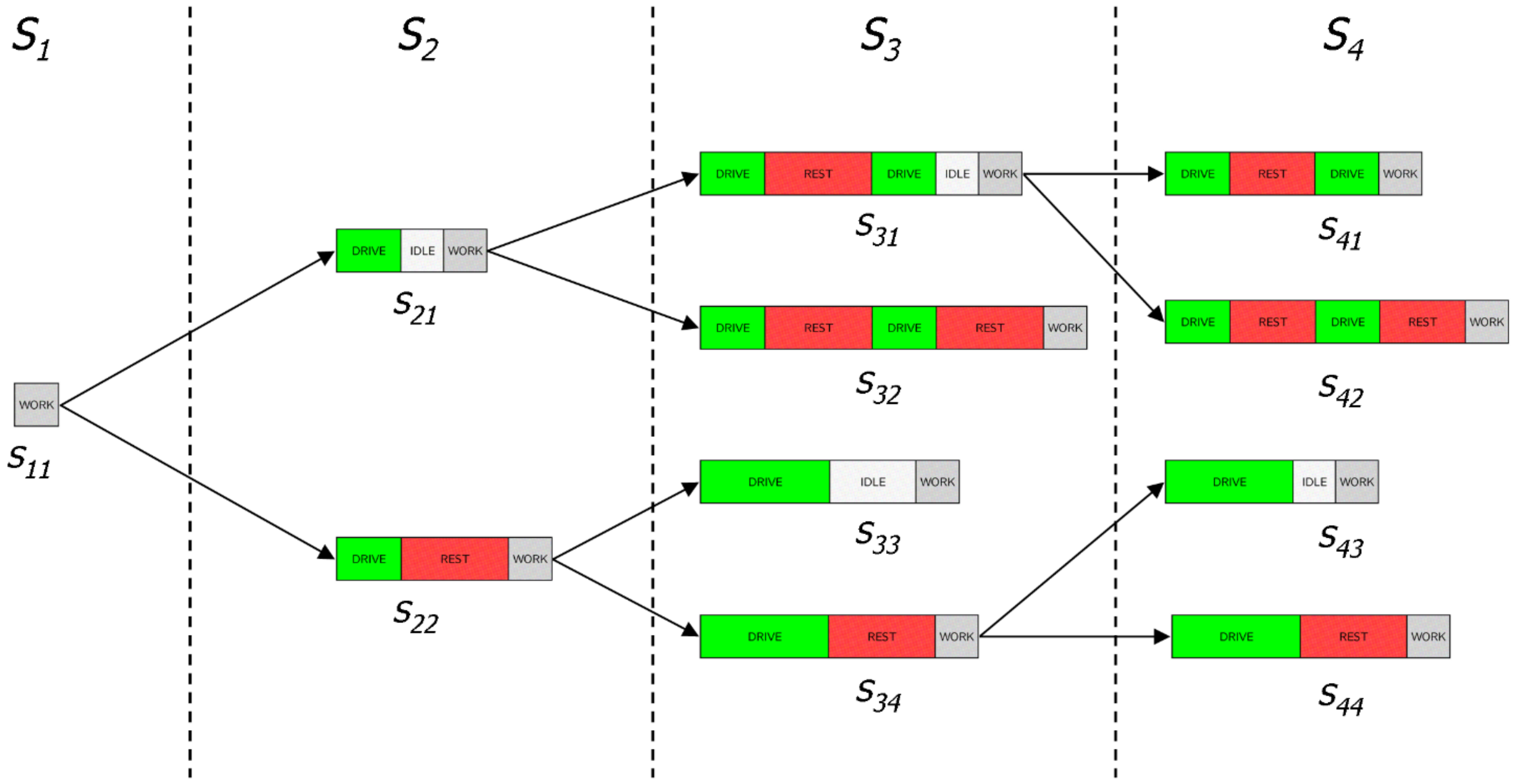
This schedule can be generated as follows:

$$((\texttt{WORK},1).(\texttt{DRIVE},6).(\texttt{IDLE},1).(\texttt{WORK},1).(\texttt{DRIVE},5).\underbrace{(\texttt{REST},10)}_{\text{Minimal duration}}.(\texttt{DRIVE},6)\underbrace{\xleftarrow{\{\texttt{REST}\}} 2)}_{\text{Duration of rest is increased to avoid waiting time}}.(\texttt{WORK},1).$$

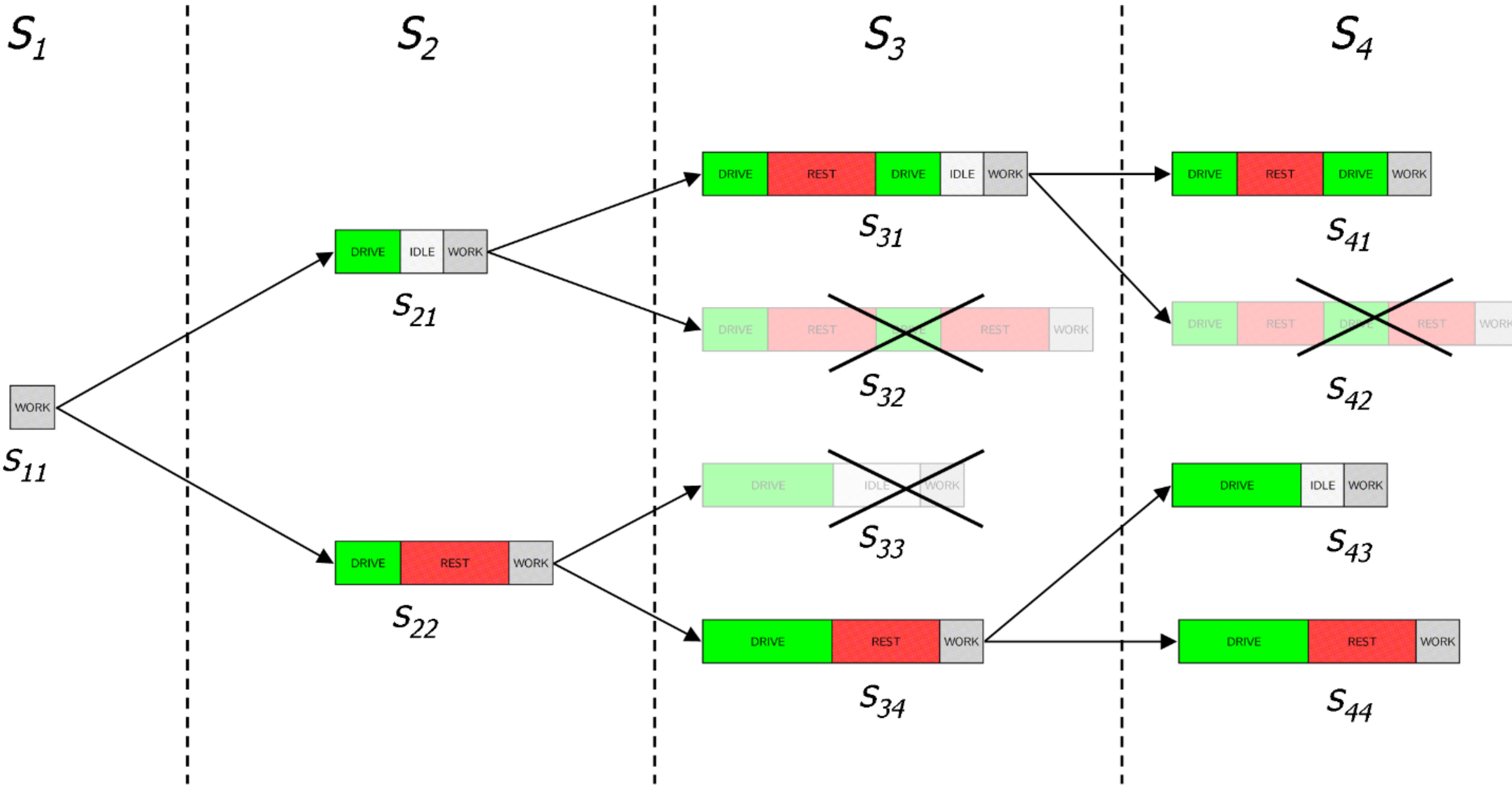
Minimal duration

Duration of rest is increased to avoid waiting time

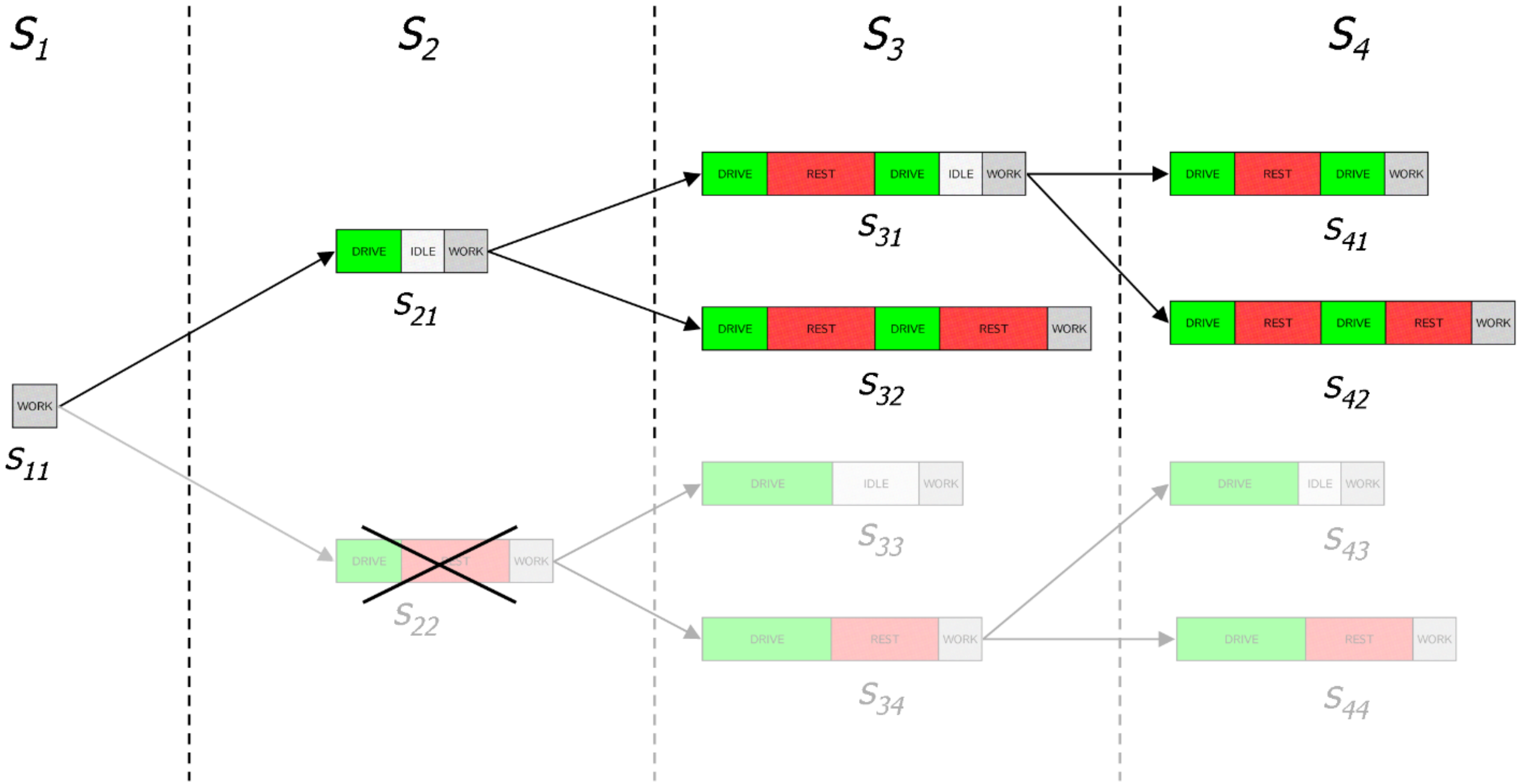
Tree Search


S1
S2
S3
S4
WORK
S11
DRIVE IDLE WORK
S21
DRIVE REST WORK
S22
DRIVE REST DRIVE IDLE WORK
S31
DRIVE REST DRIVE REST WORK
S32
DRIVE IDLE WORK
S33
DRIVE REST WORK
S34
DRIVE REST DRIVE WORK
S41
DRIVE REST DRIVE REST WORK
S42
DRIVE IDLE WORK
S43
DRIVE REST WORK
S44

Removal of dominated schedules

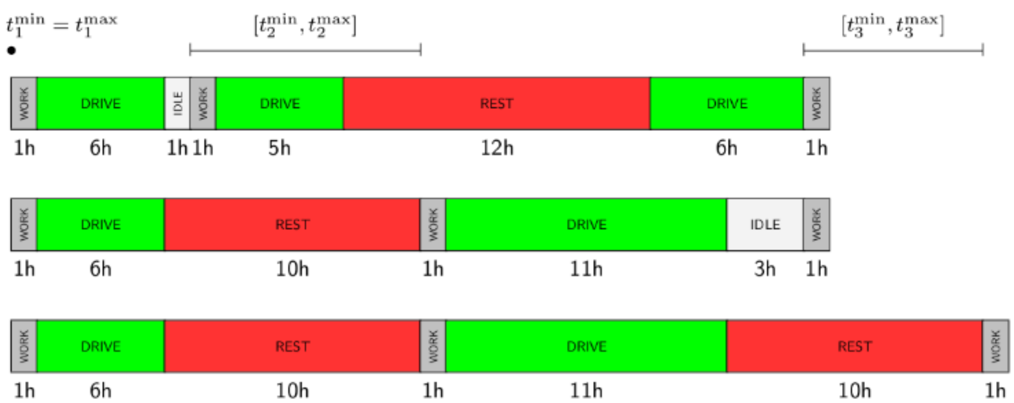


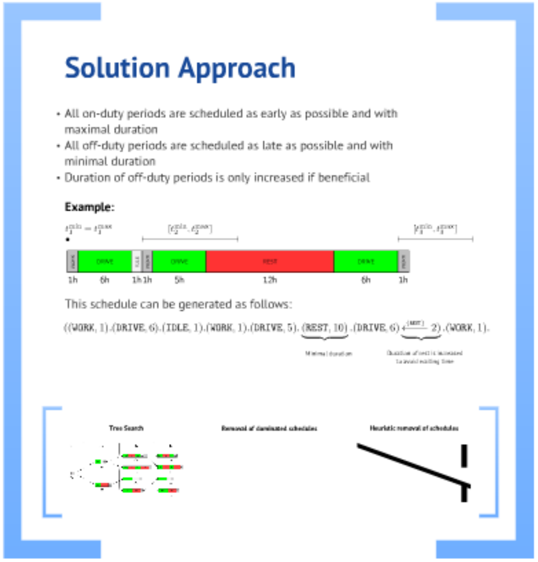
Heuristic removal of schedules



Truck Driver Scheduling

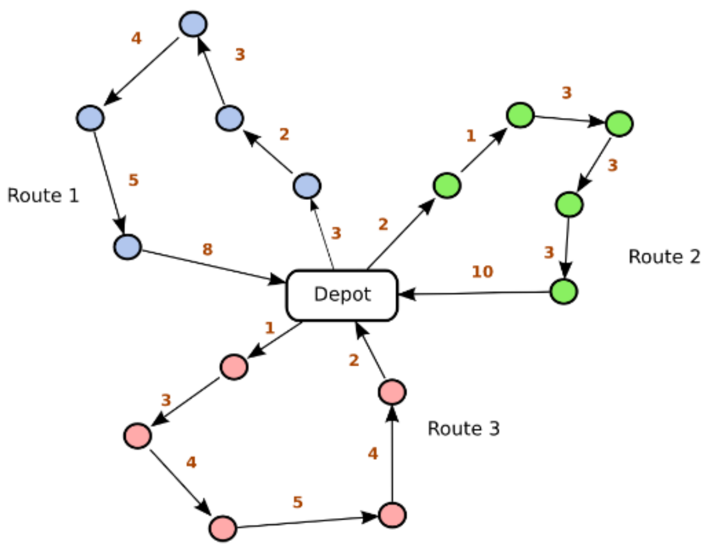
Problem:
Given a sequence of customer locations to be visited within given time windows, find a schedule complying with applicable hours of service regulations such that each customer is visited within the respective time window

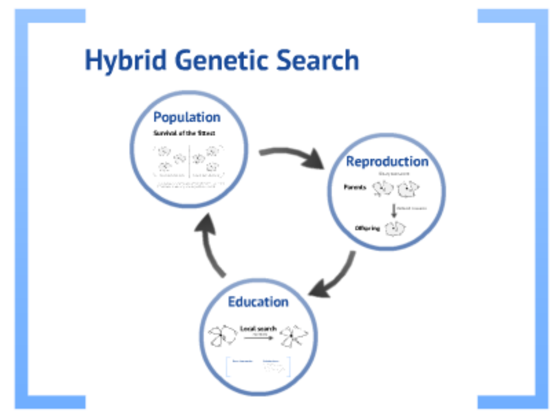


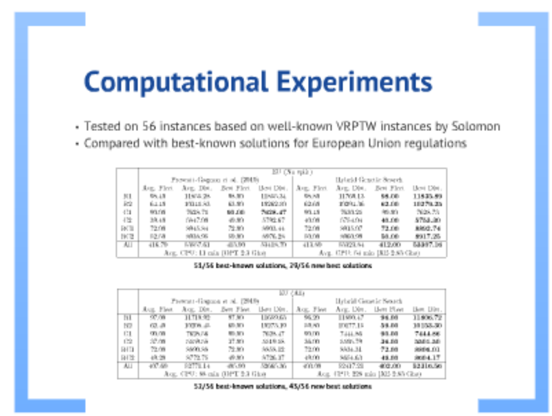


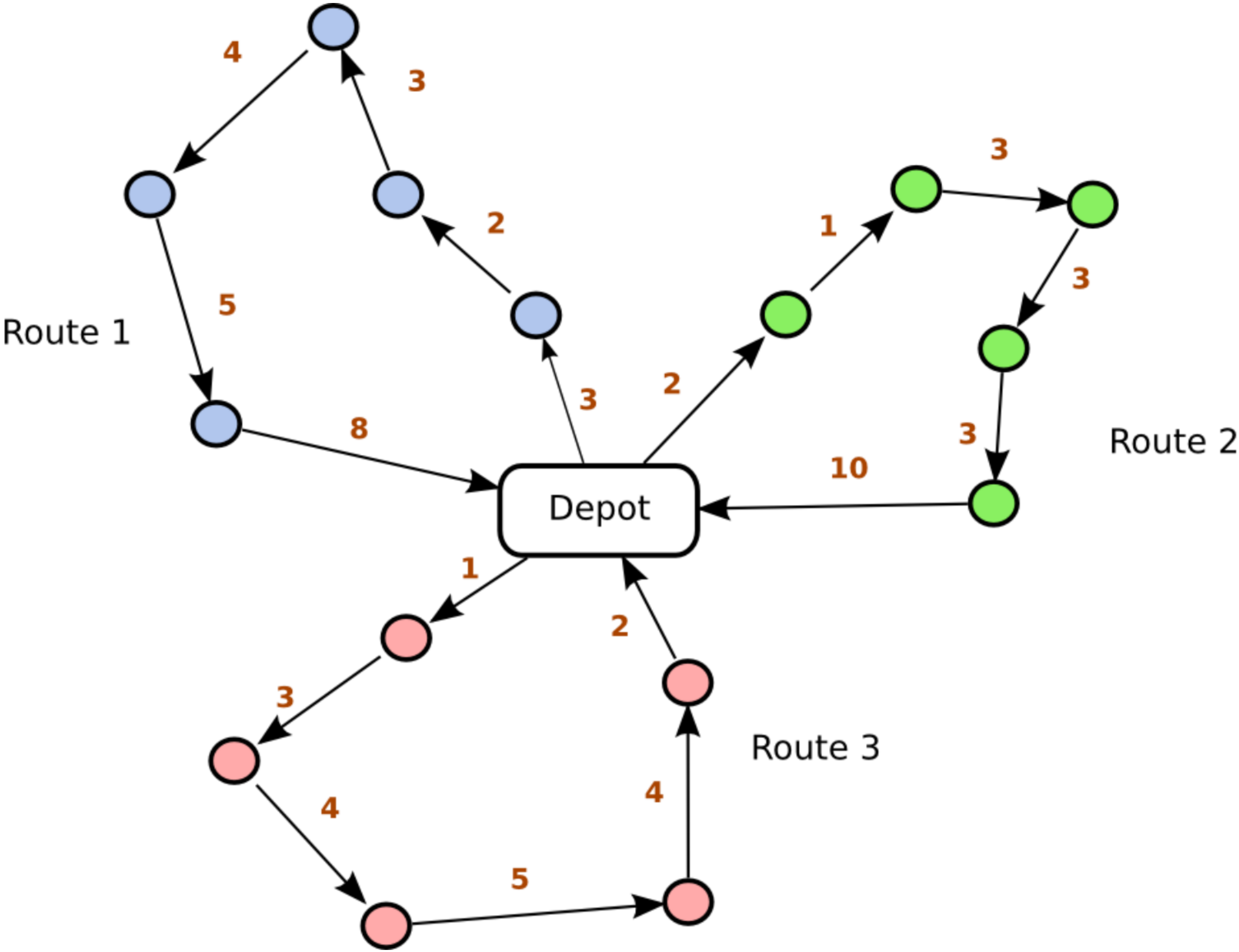
Vehicle Routing

In many applications we must consider hours of service regulations when optimising vehicle routes





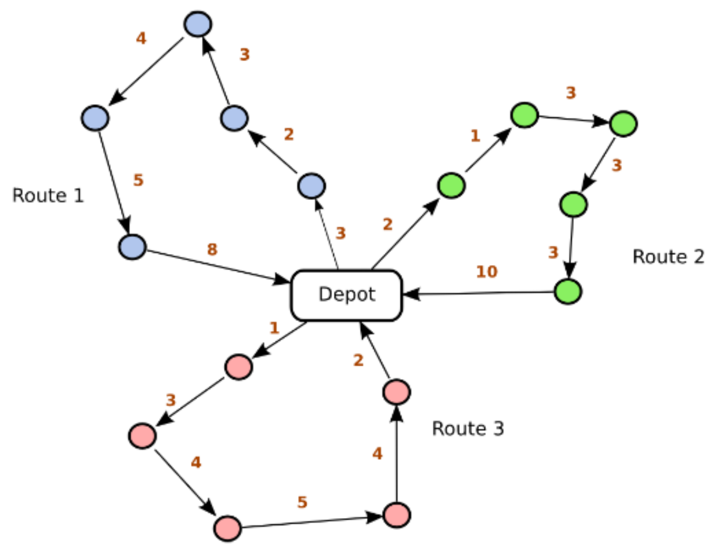


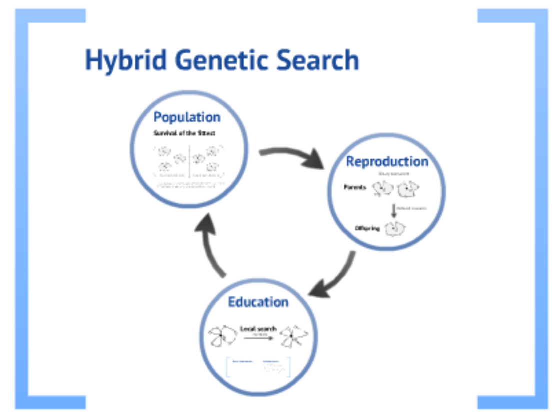


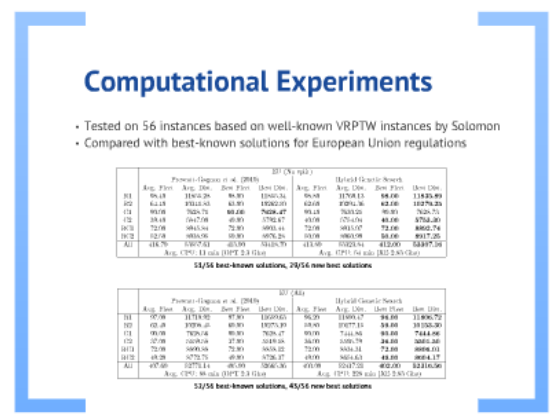
Route 1
Route 2
Route 3
Depot
4
3
2
3
5
8
1
3
3
3
2
10
1
2
3
4
5
4

Vehicle Routing

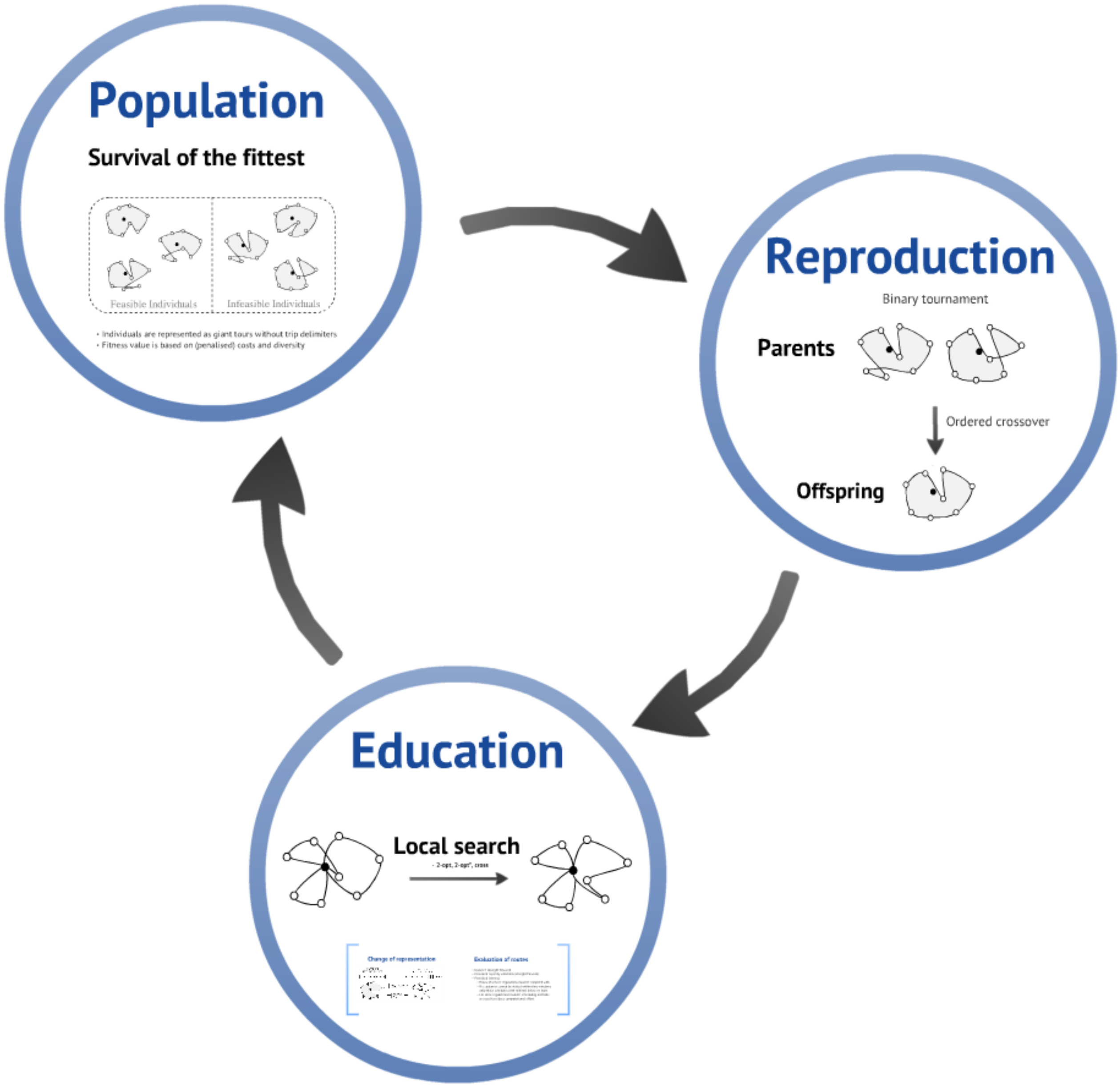
In many applications we must consider hours of service regulations when optimising vehicle routes





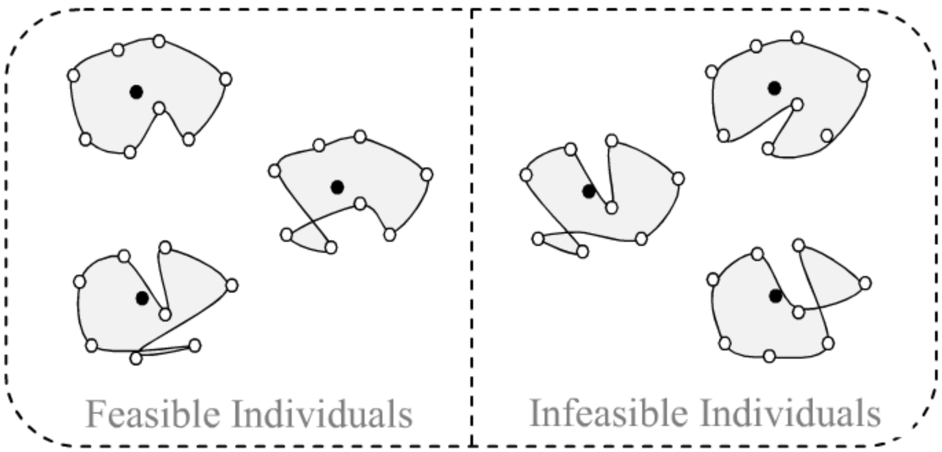


Hybrid Genetic Search

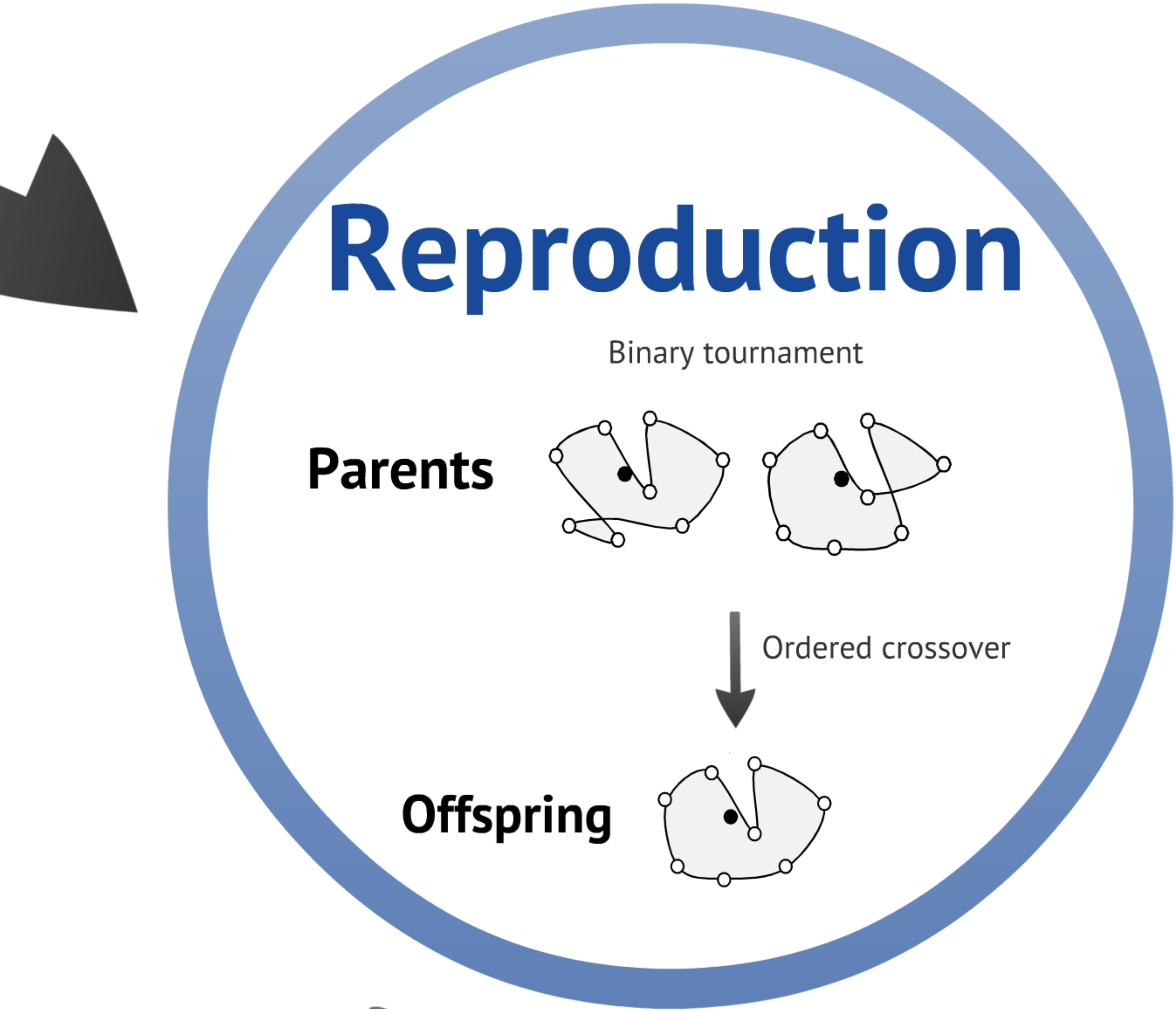


Population

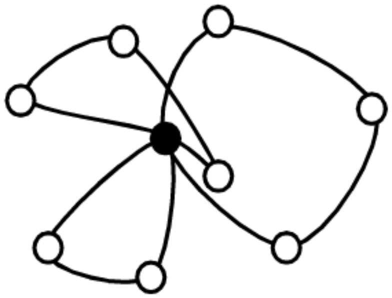
Survival of the fittest



- Individuals are represented as giant tours without trip delimiters
- Fitness value is based on (penalised) costs and diversity

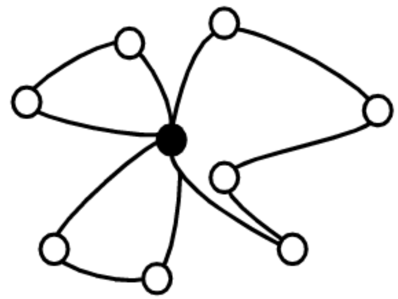

Reproduction
Binary tournament
Parents
Ordered crossover
Offspring

Education

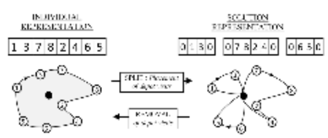


Local search

- 2-opt, 2-opt*, cross



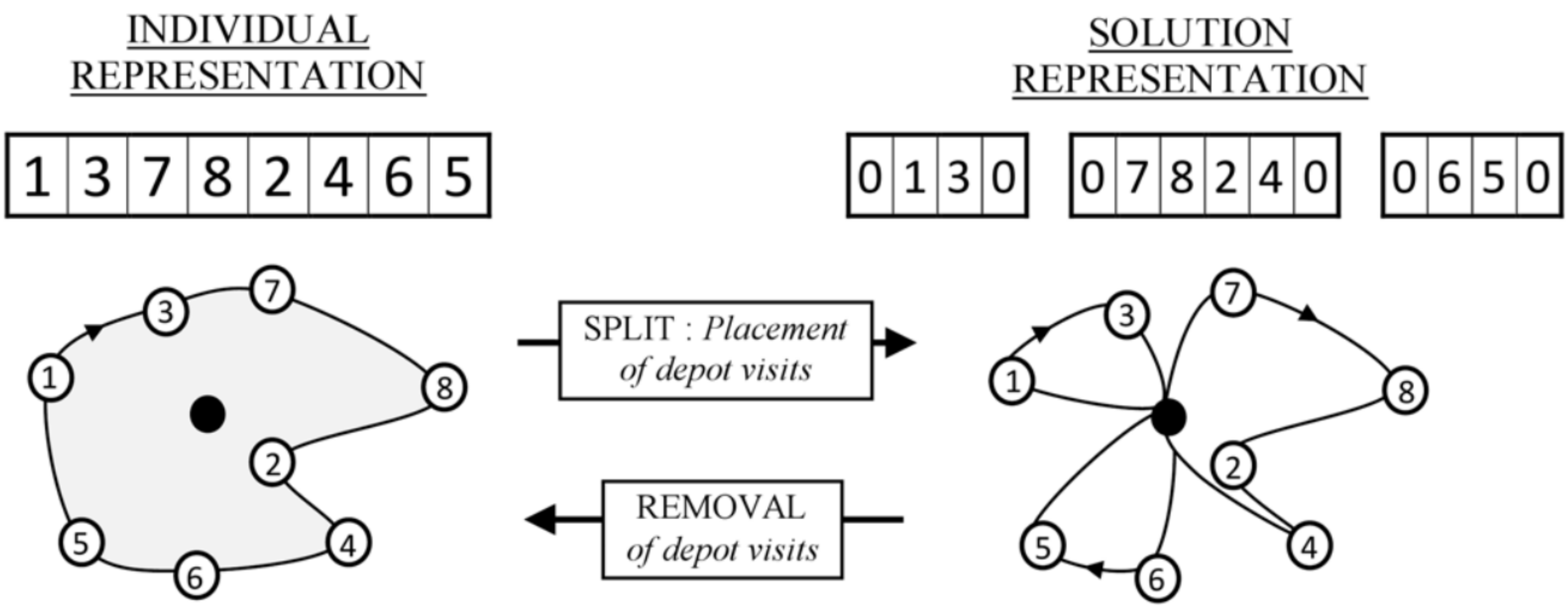
Change of representation



Evaluation of routes

- Distance (straight forward)
- Penalised capacity violations (straight forward)
- Penalised lateness
  - Hours of service regulations must be complied with
  - If a customer cannot be visited within time windows only those schedules with minimal delay are kept
  - For some regulations heuristic scheduling methods are used to reduce computational effort

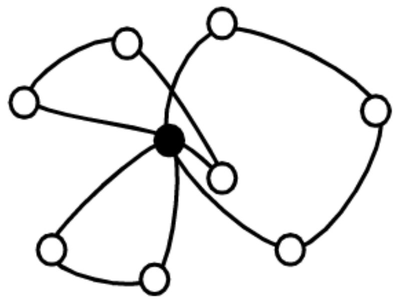
Change of representation



Evaluation of routes

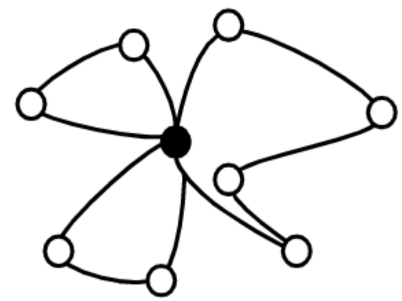
- Distance (straight forward)
- Penalised capacity violations (straight forward)
- Penalised lateness
  - Hours of service regulations must be complied with
  - If a customer cannot be visited within time windows only those schedules with minimal delay are kept
  - For some regulations heuristic scheduling methods are used to reduce computational effort

Education

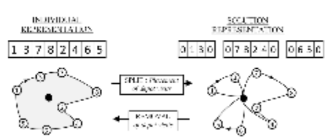


Local search

- 2-opt, 2-opt*, cross



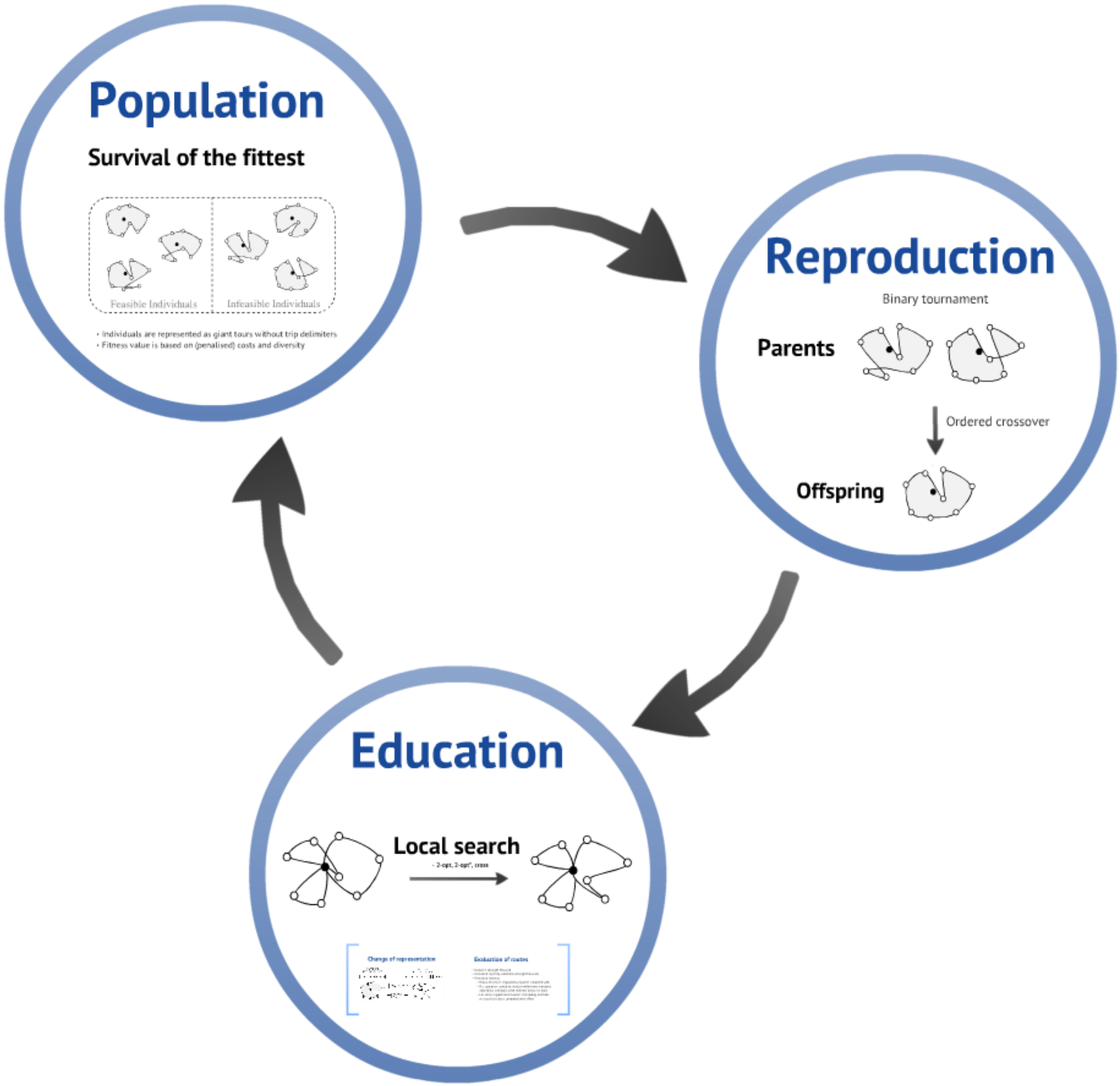
Change of representation



Evaluation of routes

- Distance (straight forward)
- Penalised capacity violations (straight forward)
- Penalised lateness
  - Hours of service regulations must be complied with
  - If a customer cannot be visited within time windows only those schedules with minimal delay are kept
  - For some regulations heuristic scheduling methods are used to reduce computational effort

Hybrid Genetic Search



Computational Experiments

- Tested on 56 instances based on well-known VRPTW instances by Solomon
- Compared with best-known solutions for European Union regulations

	EU (No split)							
	Prescott-Gagnon et al. (2010)				Hybrid Genetic Search			
	Avg. Fleet	Avg. Dist.	Best Fleet	Best Dist.	Avg. Fleet	Avg. Dist.	Best Fleet	Best Dist.
R1	98.40	11855.28	98.00	11855.34	98.80	11769.13	**98.00**	**11835.89**
R2	64.40	10341.83	63.00	10262.50	62.60	10294.36	**62.00**	**10279.25**
C1	90.00	7628.71	**90.00**	**7628.47**	90.40	7630.25	90.00	7628.73
C2	39.40	5847.00	40.00	5792.67	40.00	5754.04	**40.00**	**5753.30**
RC1	72.00	8945.84	72.00	8903.44	72.00	8915.07	**72.00**	**8892.74**
RC2	52.50	8938.95	50.00	8976.28	50.00	8960.99	**50.00**	**8917.25**
All	416.70	53557.61	413.00	53418.70	413.80	53323.84	**412.00**	**53307.16**
	Avg. CPU: 11 min (OPT 2.3 Ghz)				Avg. CPU: 54 min (XE 2.83 Ghz)			

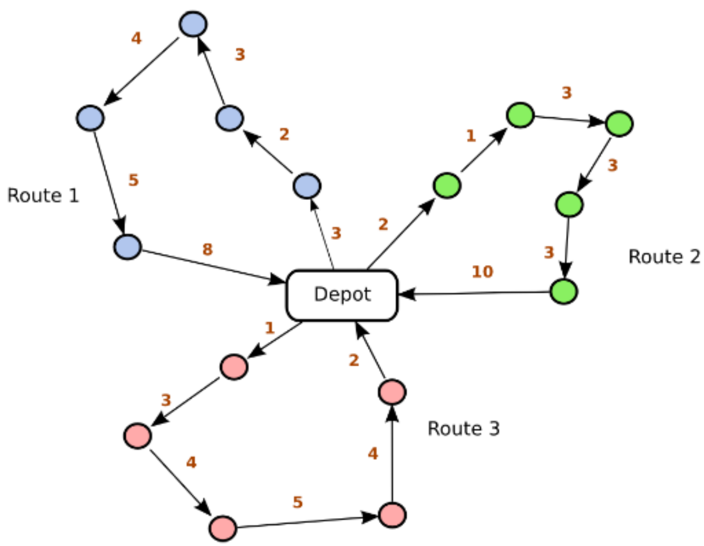
51/56 best-known solutions, 29/56 new best solutions

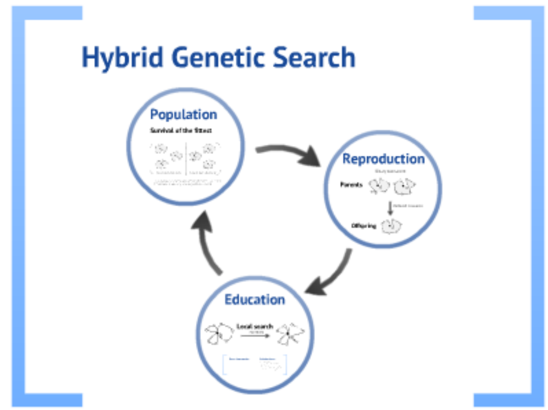
	EU (All)							
	Prescott-Gagnon et al. (2010)				Hybrid Genetic Search			
	Avg. Fleet	Avg. Dist.	Best Fleet	Best Dist.	Avg. Fleet	Avg. Dist.	Best Fleet	Best Dist.
R1	97.00	11710.92	97.00	11659.63	96.20	11800.47	**96.00**	**11806.72**
R2	62.40	10208.45	60.00	10273.19	59.80	10177.15	**59.00**	**10153.30**
C1	90.00	7628.56	90.00	7628.47	90.00	7444.86	**90.00**	**7444.86**
C2	37.00	5559.58	37.00	5519.58	36.00	5505.79	**36.00**	**5501.50**
RC1	72.00	8890.88	72.00	8858.12	72.00	8834.31	**72.00**	**8806.01**
RC2	49.20	8772.75	49.00	8726.37	49.00	8654.63	**49.00**	**8604.17**
All	407.60	52771.14	405.00	52665.36	403.00	52417.21	**402.00**	**52316.56**
	Avg. CPU: 88 min (OPT 2.3 Ghz)				Avg. CPU: 228 min (XE 2.83 Ghz)			

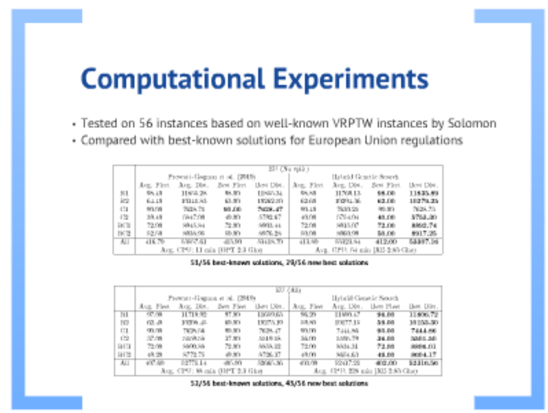
52/56 best-known solutions, 43/56 new best solutions

Vehicle Routing

In many applications we must consider hours of service regulations when optimising vehicle routes

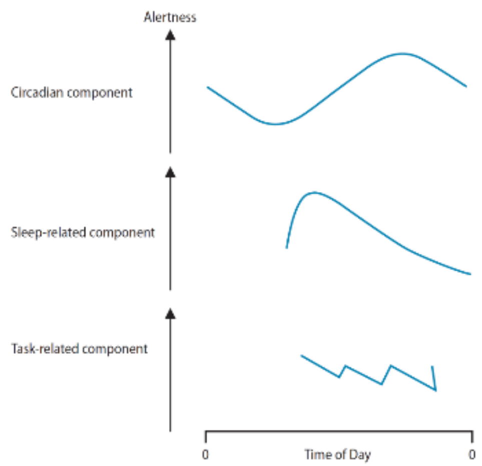


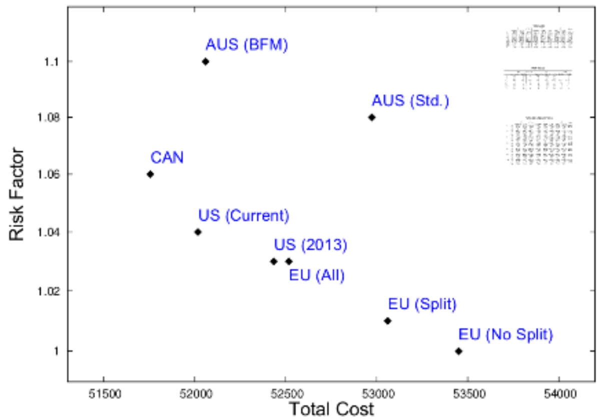


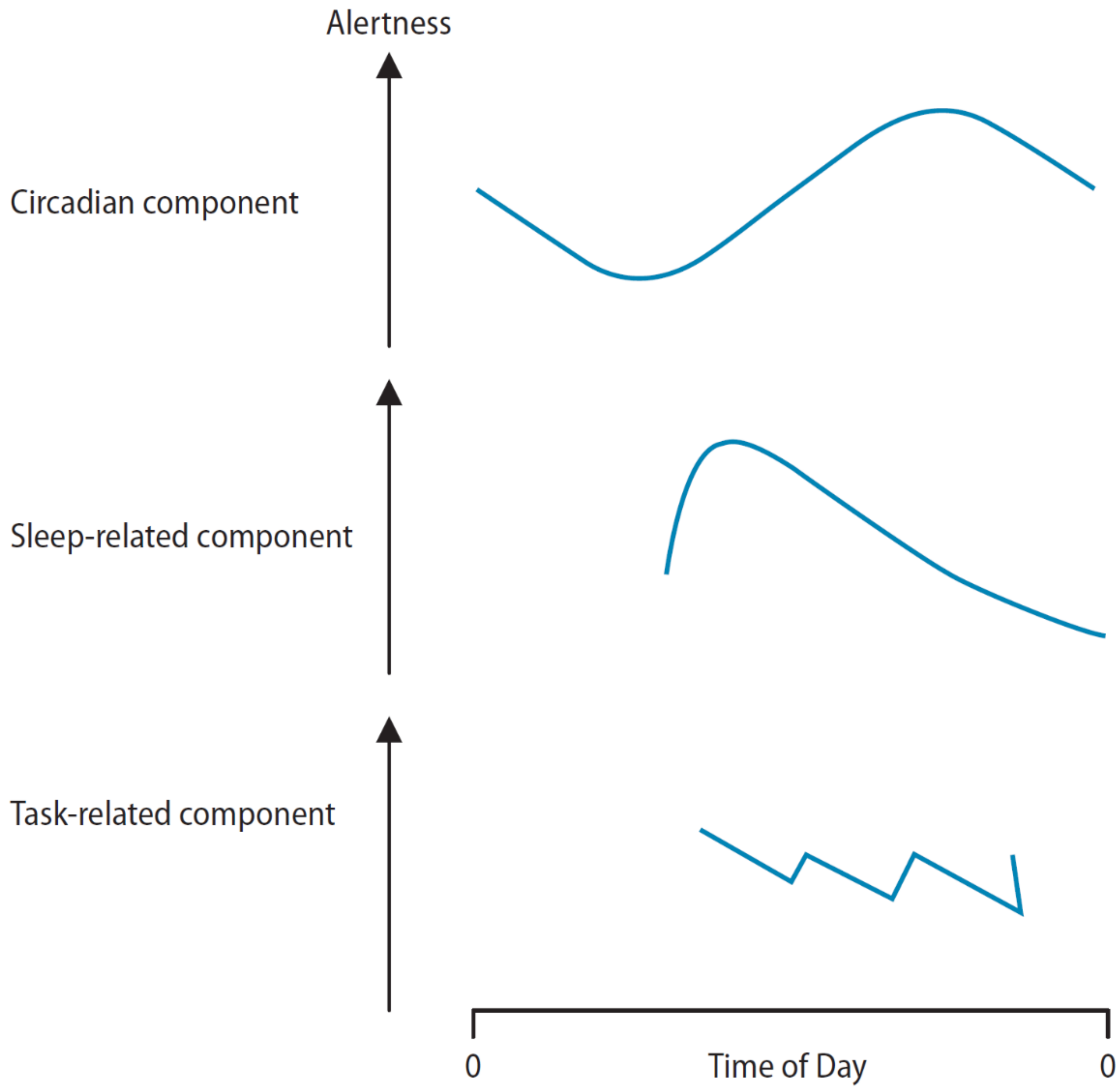


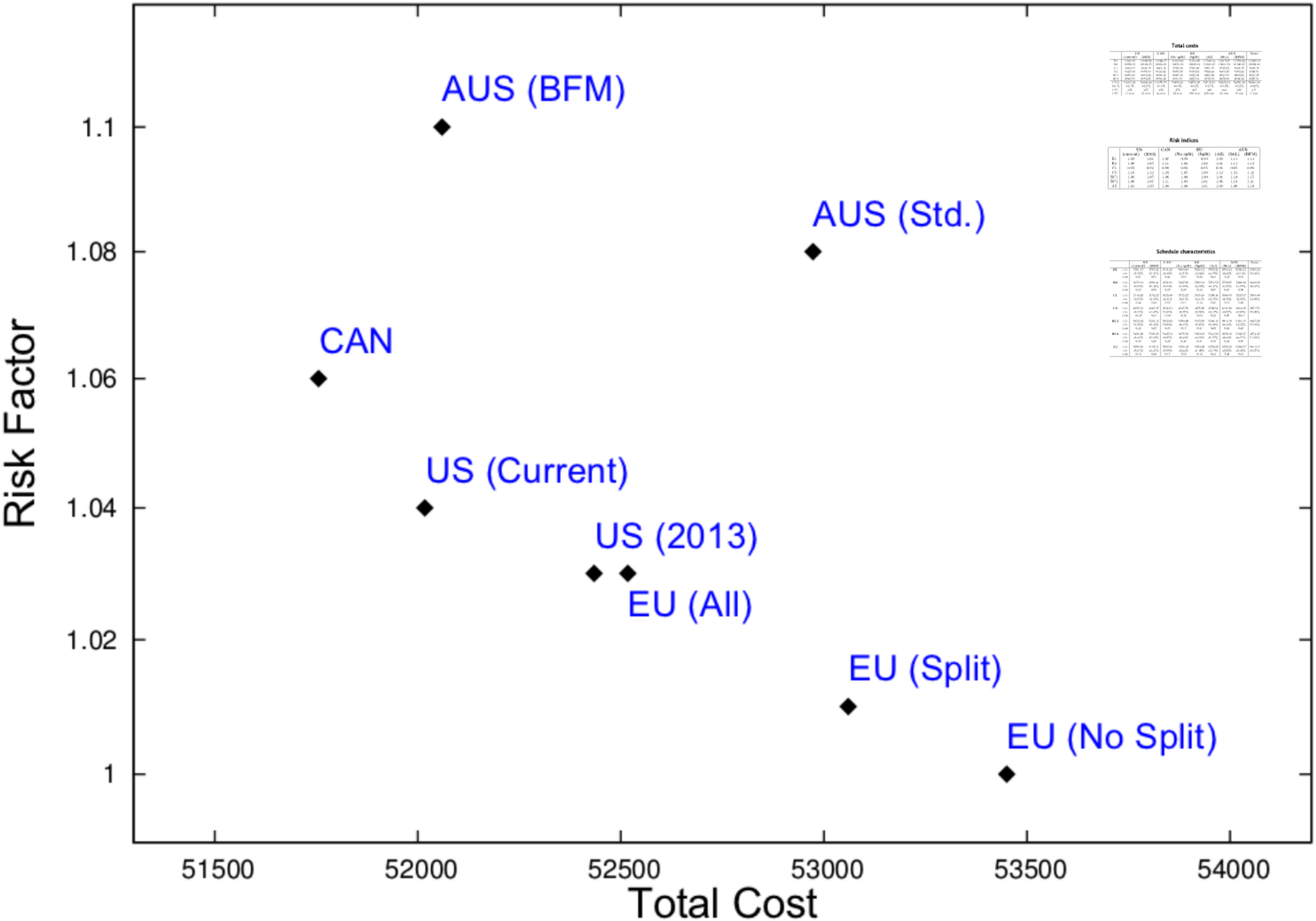
Regulatory Impact Analysis

- We assume that carrier seeks to minimise total costs
- Optimise routes for different regulations using hybrid genetic search
- Analyse solutions regarding total costs and road safety
- Fatigue/Risk Index Calculator provided by Health and Safety Executive - UK (http://www.hse.gov.uk/research/rrhtm/rr446.htm)






Alertness
Circadian component
Sleep-related component
Task-related component
0
Time of Day
0



AUS (BFM)
AUS (Std.)
CAN
US (Current)
US (2013)
EU (All)
EU (Split)
EU (No Split)
Risk Factor
1.1
1.08
1.06
1.04
1.02
1
Total Cost
51500
52000
52500
53000
53500
54000
Total costs
Risk indices
Schedule characteristics

Total costs

	US (current)	US (2013)	CAN	EU (No split)	EU (Split)	EU (All)	AUS (Std.)	AUS (BFM)	None
R1	11666.19	11690.82	11688.77	11817.42	11764.29	11748.14	11819.65	11752.88	11620.10
R2	10078.91	10123.65	10074.01	10276.13	10232.13	10181.37	10261.73	10180.27	10002.36
C1	7447.15	7447.15	7447.14	7637.43	7636.20	7451.15	7625.02	7447.15	7447.15
C2	5427.60	5655.66	5124.82	5857.09	5677.43	5533.44	5466.39	5153.82	4730.51
RC1	8856.83	8863.28	8868.42	8945.68	8922.60	8892.30	8921.56	8890.82	8821.35
RC2	8540.56	8653.45	8552.40	8916.51	8827.14	8710.67	8878.58	8634.84	8325.21
CTD	52017.23	52434.00	51755.55	53450.26	53059.78	52517.07	52972.93	52059.78	50946.68
Inc %	+2.1%	+2.9%	+1.6%	+4.9%	+4.2%	+3.1%	+4.0%	+2.2%	+0.0%
CNV	432	437	430	452	447	440	444	432	411
CPU	11 min	21 min	64 min	23 min	180 min	228 min	26 min	19 min	7 min

Risk indices

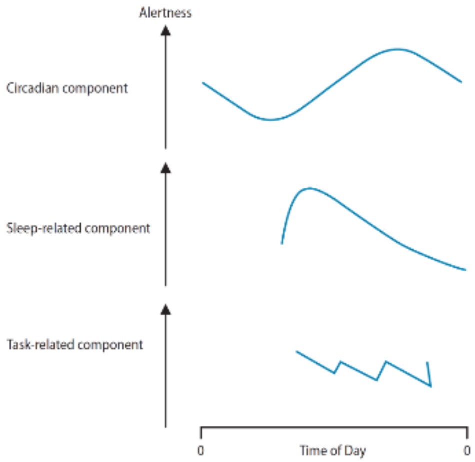
	US		CAN	EU			AUS	
	(current)	(2013)		(No split)	(Split)	(All)	(Std.)	(BFM)
R1	1.03	1.04	1.07	0.99	0.99	1.03	1.11	1.14
R2	1.08	1.05	1.11	1.02	1.02	1.04	1.11	1.13
C1	0.93	0.92	0.88	0.92	0.95	0.94	0.85	0.86
C2	1.18	1.12	1.26	1.07	1.09	1.12	1.34	1.42
RC1	1.06	1.05	1.08	1.00	1.00	1.04	1.10	1.15
RC2	1.08	1.07	1.11	1.03	1.04	1.08	1.16	1.21
All	1.04	1.03	1.06	1.00	1.01	1.03	1.08	1.10

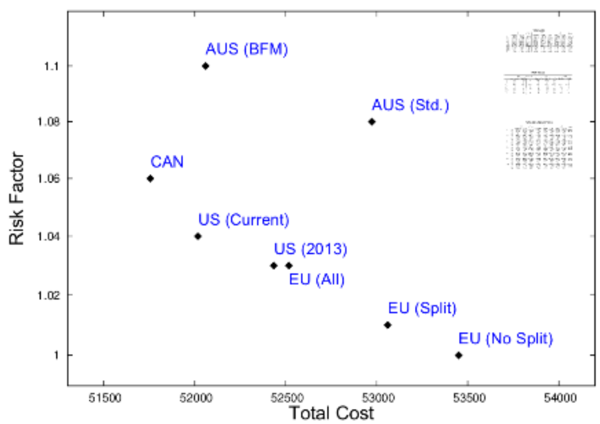
Schedule characteristics

		US (current)	US (2013)	CAN	EU (No split)	EU (Split)	EU (All)	AUS (Std.)	AUS (BFM)	None
R1	CSD	7701:17	7781:22	7614:30	8493:44	8226:12	7897:22	8791:03	8203:23	6976:20
	OD	45.72%	45.31%	46.30%	41.81%	43.04%	44.79%	40.40%	43.13%	50.34%
	OBR	9:01	8:56	9:04	7:56	8:20	8:46	7:47	8:19	
R2	CSD	6676:13	6866:41	6654:21	7487:26	7296:31	7051:50	7652:05	7482:32	6423:20
	OD	46.50%	45.34%	46.64%	41.99%	42.97%	44.31%	41.05%	41.76%	48.10%
	OBR	9:23	8:59	9:27	8:29	8:33	9:05	8:01	8:09	
C1	CSD	7110:20	7152:27	6973:48	7572:27	7476:26	7308:34	7404:59	7237:57	7054:48
	OD	33.55%	33.35%	34.21%	32.01%	32.41%	32.65%	32.70%	32.96%	33.82%
	OBR	6:42	6:33	6:57	6:11	6:14	6:26	5:17	5:22	
C2	CSD	4025:31	4645:37	3564:01	4945:59	4875:29	4508:54	4631:22	3814:39	2951:55
	OD	46.71%	41.45%	51.06%	39.75%	39.59%	42.17%	40.77%	47.86%	58.98%
	OBR	10:37	9:31	11:10	8:32	9:03	9:32	9:05	10:31	
RC1	CSD	5022:03	5201:13	5052:00	5784:08	5673:59	5204:16	5816:18	5391:15	4607:28
	OD	51.09%	49.36%	50.84%	44.67%	45.45%	49.44%	44.34%	47.72%	55.54%
	OBR	9:42	9:27	9:25	8:17	8:21	9:08	8:03	8:48	
RC2	CSD	5386:09	5535:45	5347:53	6075:56	5952:10	5541:58	6058:10	5639:57	4753:37
	OD	46.47%	45.62%	46.85%	42.43%	43.01%	45.77%	42.43%	44.71%	51.74%
	OBR	9:36	9:26	9:28	8:34	8:41	9:19	8:34	8:56	
All	CSD	5986:56	6197:11	5867:46	6726:37	6583:28	6252:09	6725:39	6294:57	5461:15
	OD	45.01%	43.41%	45.98%	40.44%	41.08%	43.19%	40.28%	43.02%	49.75%
	OBR	9:10	8:48	9:15	7:60	8:12	8:43	7:48	8:21	

Regulatory Impact Analysis

- We assume that carrier seeks to minimise total costs
- Optimise routes for different regulations using hybrid genetic search
- Analyse solutions regarding total costs and road safety
- Fatigue/Risk Index Calculator provided by Health and Safety Executive - UK (http://www.hse.gov.uk/research/rrhtm/rr446.htm)





Hours of Service Regulations in Road Transport

Fatigue

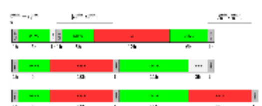
Truck driver fatigue is internationally recognised as a significant factor in 15-20% of all commercial road transport crashes

To improve road safety governments world wide are adopting stricter hours of service regulations for truck drivers

Some regulations introduce a "chain of responsibility" so that dispatchers can be made liable for unrealistic schedules

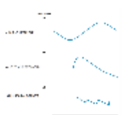
Truck Driver Scheduling

Problem:
Given a sequence of customer locations to be visited within given time windows, find a schedule complying with applicable hours of service regulations such that each customer is visited within the respective time window



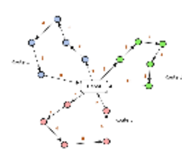
Regulatory Impact Analysis

- We assume that carrier seeks to minimise total costs
- Optimise routes for different regulations using hybrid genetic search
- Analyse solutions regarding total costs and road safety
- Fatigue/Risk Index Calculator provided by Health and Safety Executive - UK (http://www.hse.gov.uk/research/rrhtm/rr446.htm)



Vehicle Routing

In many applications we must consider hours of service regulations when optimising vehicle routes



Asvin Goel, Thibaut Vidal

Seminar UFPB,
15 March 2013

ZARAGOZA LOGISTICS CENTER
UNIVERSITAT LEIPZIG
LPZ E-BUSINESS applied telematics
Université de Montréal
utt université de technologie Troyes
CIRRELT
CONSEIL RÉGIONAL CHAMPAGNE ARDENNE

Thank you very much for your attention !!

For further reading :

- A. Goel and T. Vidal, Hours of Service Regulations in Road Freight Transport: An Optimization-based International Assessment (2012), CIRRELT Tech. Rep. 2012-08.
- A. Goel and L. -M. Rousseau, Truck Driver Scheduling in Canada (2012), in: Journal of Scheduling (to appear)
- A. Goel and L. Kok, Truck Driver Scheduling in the United States (2012), in: Transportation Science (to appear)
- A. Goel, C. Archetti and M. Savelsbergh, Truck Driver Scheduling in Australia (2012), in: Computers & Operations Research, 39:5(1122-1132)
- A. Goel, Truck Driver Scheduling in the European Union (2010), in: Transportation Science, 44:4(429-441)
- A. Goel, Vehicle Scheduling and Routing with Drivers' Working Hours (2009), in: Transportation Science, 43:1(17--26)