Università della Svizzera italiana

Scuola universitaria professionale della Svizzera italiana

IDSIA
Istituto Dalle Molle di studi sull'intelligenza artificiale

Vehicle Routing Problems with ACO: from research to applications

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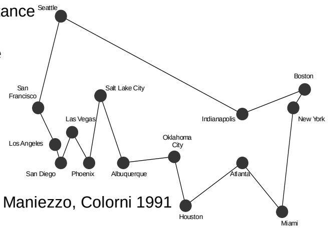
Traveling Salesman Problems

Problem: given N cities, and a distance function d between cities, find a tour that:
(1) goes through every city once and only once
(2) minimizes the total distance

■ Problem is NP-complete

■ Classical combinatorial optimization problem to test algorithms

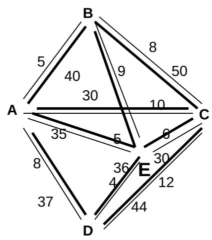


First application, Dorigo, Maniezzo, Colorni 1991

Search Space

To each edge is associated a *static value* returned by an heuristic function *h*(*r*,*s*) based on the edge-cost (TSP inverse of the distance)

Each edge of the graph is augmented with a pheromone trail $\tau(r,s)$ deposited by ants. *Pheromone is dynamic* and it is learned at run-time (from the same τ_0)



Goodness(r,s) = $f(\tau(r,s)$, $h(r,s))$
= $\tau(r,s)$ * 1/distance(r,s)) for TSP

Ant Colony System for the TSP

Initialize the pheromone for each couple of cities
Loop
  Randomly position *m* artificial ants on n cities
  For city=1 to n
    For ant=1 to m
      State Transition Rule: Select probabilistically the next city according to pheromone and distance
      Locally update the pheromone of the chosen edge
    End for
  End for
  Apply local search to the complete solution
  Globally Update pheromone value along the path of the best ant
Until End_condition

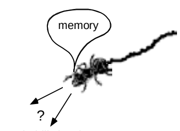
Dorigo M., Gambardella L.M, Ant Colony System: A Cooperative Learning Approach to the TSP, *IEEE Transactions on Evolutionary Computation* Vol. 1,No. 1,pp. 53-66, 1997

ACS State Transition rule

Next city is chosen between the not visited cities according to a probabilistic rule

Exploitation: the best edge is chosen

Exploration: one of the edge in proportion to its value



ACO state transition rule: formulae

$$s = \begin{cases} \arg\max_{u \in J_k(r)} \left\{ [\tau(r,u)] \cdot [\eta(r,u)]^{\beta} \right\} & \text{if } q \le q_0 \quad \text{(Exploitation)} \\ S & \text{otherwise (Exploration)} \end{cases}$$

where
- S is a stochastic variable distributed as follows:

$$p_k(r,s) = \begin{cases} \dfrac{[\tau(r,s)] \cdot [\eta(r,s)]^{\beta}}{\sum_{u \in J_k(r)} [\tau(r,u)] \cdot [\eta(r,u)]^{\beta}} & \text{if } s \in J_k(r) \\ 0 & \text{otherwis} \end{cases}$$

- τ is the trail
- η is the inverse of the distance
- $J_k(r)$ is the set of cities still to be visited by ant k positioned on city r
- β and q_0 are parameters

ACS local trail updating

At each step the chosen edge is locally updated

$$\tau(r,s) \leftarrow (1-\alpha)\,.\,\tau(r,s) + \alpha\,.\;\; \tau_0$$

Where the initial value for τ_0 is

$$\tau_0 = \frac{1}{\text{Ncities.NearestNeighborhood}}$$

ACS global trail updating

At the end of each iteration the best ant so far reinforces its decisions by updating all the edges belonging to the best tour with the pheromone proportional to the length of the tour

$$\tau(r,s) \leftarrow (1-\alpha)\cdot\tau(r,s) + \alpha\cdot\Delta\tau(r,s)_{Global}$$

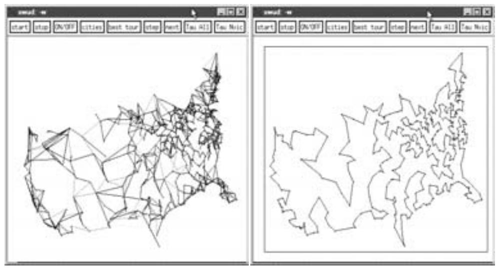
where

$$\Delta\tau(r,s)_{Global} = \frac{1}{L_{best}}$$

The original Ant System for the TSP

Initialize the pheromone for each couple of cities
Loop
  Randomly position *m* artificial ants on n cities
  For city=1 to n
    For ant=1 to m
      Random Proportional State Transition Rule:
      Select probabilistically the next city
      End for
  End for
  Evaporates the pheromone of all edges of (1-alfa)
  Globally Update pheromone value along paths of all ants
Until End_condition

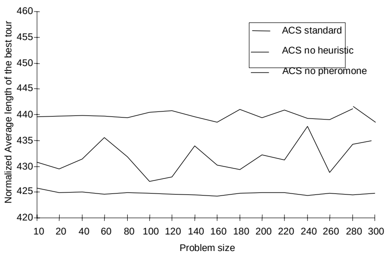
Dorigo Colorni Maniezzo, 1991



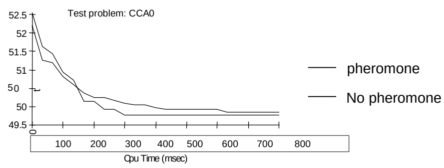
Best solutions structures emerge step by step from the computation

Among the state of the art algorithms for TSP and ATSP problems

Pheromone is useful?

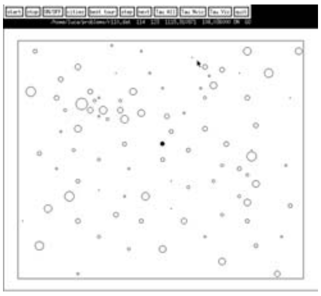


Effectiveness of distributed pheromone learning



Best tour length as a function of elapsed CPU time (avg on 100 runs)

Vehicle Routing Problems



Clients
Requested quantity
Delivery Time Windows
Pick-up and delivery
Access Limitation
Allow to split delivery

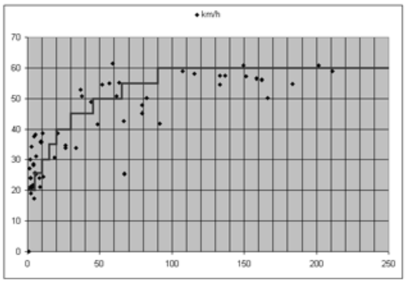
Distribution Problems

Fleet
Number of vehicles
Fleet composition
Size
Non-homogeneous vehicles
Internal/external trucks
Costs (fix and variable)
Depot time windows
Number of drivers
Driver rest period
Time limitation

Distribution Problems

Other Information
Number of depots
Streets graph
Traveling distances
Traveling time
Traffic information
Speed model

Speed Model

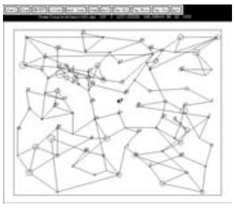


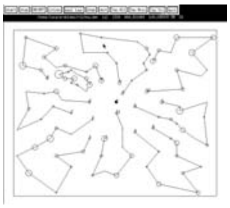
Speed - Distances		
0 – 5 km	=>	20 km/h
5 – 10 km	=>	25 km/h
10 – 15 km	=>	30 km/h
15 – 20 km	=>	35 km/h
20 – 30 km	=>	40 km/h
30 – 45 km	=>	45 km/h
45 – 65 km	=>	50 km/h
65 – 90 km	=>	55 km/h
90 ... km	=>	60 km/h

Transport Problems

Objectives: (also multiples)
•To design a set of route
•Total distance minimization
•Travel time minimization
•Number of vehicles minimization
•Fleet optimization

… cost function minimization





Academic Vehicle Routing Problems

CVRP (capacitated)
is defined on a graph G=(V,E) where
V={0, …, n} is the vertex set where 0 is the depot.

To each vertex V\{0} is associated
a non negative demand q_i
and to each edge (*i*,*j*) is associated a cost c_{ij}.

Goal: design *m* vehicle routes of least cost, each starting and ending at the depot, such as:

VRP Constraints

Each customer is visited only once

The total demand of any route does not exceed the vehicle capacity *Q*

The length of any route does not exceed a pre-set maximal route length *L*

In some version *m* is fixed a priori in other is a decision variable

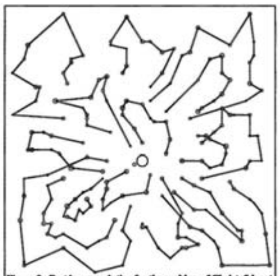


Figure 2 : Best known solution for the problem of Christofides et al. (1979) with 199 customers.

Vehicle Routing Problems with TW

VRPTW (vehicle routing with time windows). It starts from CVRP.

In addition to CVRP each customer is associated with a time window interval [min-time$_i$ max-time$_i$].

If you arrive before min-time$_i$ you have to wait and you are not allowed to arrive after max-time$_i$ (hard TWs)

With soft time windows the violation is a cost in the objective function

Goals (2): first minimize the number of vehicles and second the total distance. Initial solution NP-Hard

Gambardella 2005, Vehicles Routing with Ant Colony Optimization

Pick-up and delivery

Based on CVRP or VRPTW

Each transport has a pick-up point and a delivery point.

Some type:

•All Pick-ups first and all deliveries second

•Mixed pick-up and delivery

Goals: different definitions based on the formulation

Gambardella 2005, Vehicles Routing with Ant Colony Optimization

VRP approaches

Exact Approach (up to 100 nodes)
- **Branch and bound (Fisher 1994)**

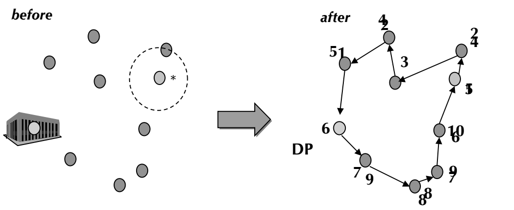
Approximation
- **Clark and Wright (1964)**
- **Hierarchical Approach (split + TSP)**
  - **Fisher & Jaikumur (1981)**
  - **Taillard (1993)**
- **Multi-route Improvement Heuristics**
  - **Kinderwater and Savelsbergh (1997)**

MetaHeuristics
- **Tabu search, Rochat and Taillard (1995)**
- **Constraint Programming, Shown (1998)**
- **Tabu search Kelly and Xu (1999)**
- **Granular Tabu, Toth & Vigo (1998)**
- **Ant System, Gambardella & al. (1999)**

Gambardella 2005, Vehicles Routing with Ant Colony Optimization

NEAREST NEIGHBOR

Procedure: starting from one of the points, iteratively connect the last visited point with the closest unvisited point



(*) starting point

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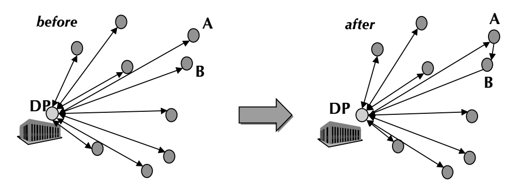
SAVINGS

Initial condition: each node is connected with one edge to the depot

Constructive procedure: add step by step the node with the highest saving in term of distance



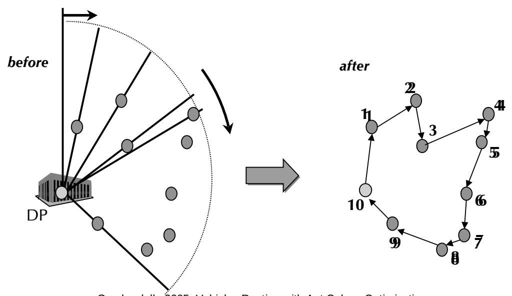
Saving *max* = 2 x [(DP-A) + (DP-B)] - [(DP-A) + (A-B) + (B-DP)] =

= (DP-A) + (DP-B) - (A-B)

Gambardella 2005, Vehicles Routing with Ant Colony Optimization

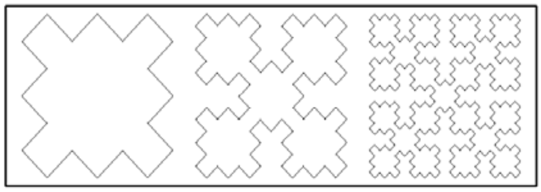
ANGLE

Constructive procedure: node sequence is generated following a semi-line that rotates



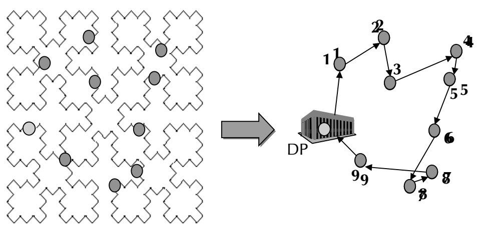
SPACE FILLING CURVE

"A space filling curve is a continuous mapping from a lower-dimensional space into a higher-dimensional one. A famous space filling curve (due to Sierpinski), is formed by repeatedly copying and shrinking a simple pattern"



SPACE FILLING CURVE

Costructive procedure: the curve is over impose on the points. Each point is associated to the closest line. The line is followed and the points are chosen accordingly.

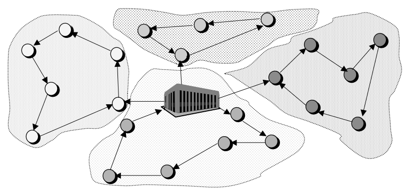


TWO PHASES APPROACH

Clustering → Routing

1. Clustering:

2. Routing:

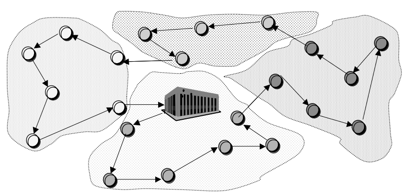


TWO PHASES APPROACH

Routing → Clustering

1. Routing:

2. Clustering:



How to solve a complex problem: we propose to use metaheuristics: find good approximation in short time

The main idea is to iteratively explore the search space

- generate some initial problem solutions (previous slides)
- evaluate their quality
- discard bad solutions and use the best to generate again
- until a terminal condition is met (usually time)

These algorithms learn from experience and are usually inspired by natural process such as

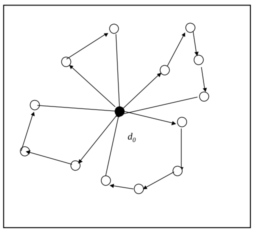
We focus on
Ant Colony System optimization

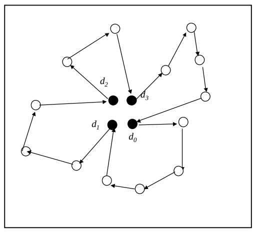
MACS-VRPTW: Vehicle Routing Problem with Time Windows, Gambardella, Taillard, Agazzi, 1999

Goal: minimize the number of vehicles and minimize the travelling distance

Ant Colony Optimization

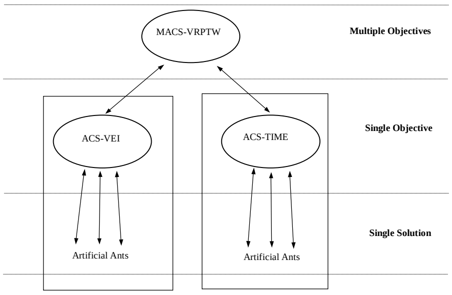
MACS-VRPTW: Vehicle Routing Problem with Time Windows, Gambardella, Taillard, Agazzi, 1999





VRPTW is transformed into a TSP by adding m-1 new depots

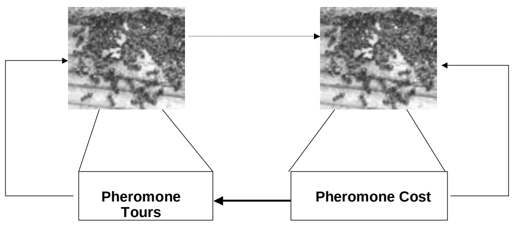
MACS-VRPTW (Gambardella et al.1999)



VRP-TW: in case of vehicles and distance minimization two ant colonies are working in parallel on the two objective functions

MACS-VRPTW (Gambardella et al.1999)

Tours minimization | Cost minimization

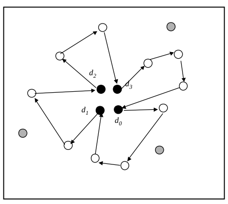


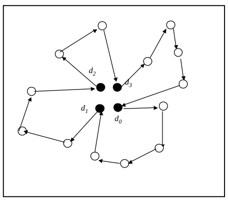
Search for a new feasible solution with one vehicle less

Minimize the cost of a feasible solution

MACS-VRPTW (Gambardella et al.1999)

Unfeasible solutions are repaired by insertion procedures

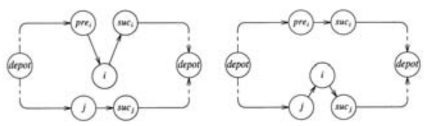




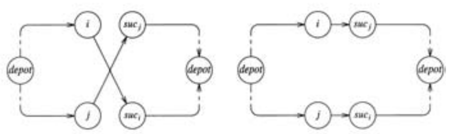
Feasible solutions are improved with local search procedures

Multi-Route Improvement Heuristic

Kinderwater and Savelsbergh (1997)



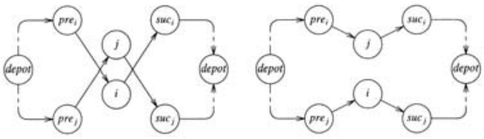
Customers relocation



Crossover

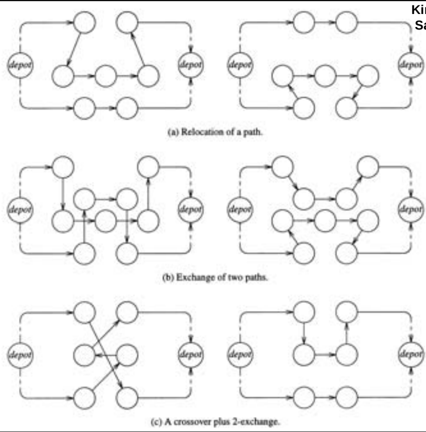
Multi-Route Improvement Heuristic

Kinderwater and Savelsbergh (1997)



Customers exchange

Kinderwater and Savelsbergh (1997)

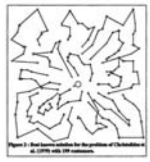


Benchmark problems

With Time Windows (TSPLIB)

56 problems (Solomon, 1987) of six different types (C1,C2,R1,R2,RC1,RC2).

Each data set contains between eight to twelve 100-node problems.



•C = clustered customers with easy TW.

•R = customers location generated uniformly randomly over a square.

•RC = a combination of randomly placed and clustered customers.

•Sets of type 1 have narrow time windows and small vehicle capacity.

•Sets of type 2 have large time windows and large vehicle capacity.

	R1		C1		RC1		R2		C2		RC2	
	VEI	DIST	VEI	DIST	VEI	DIST	VEI	DIST	VEI	DIST	VEI	DIST
MACS-VRPTW	**12.00**	1217.73	**10.00**	**828.38**	11.63	1382.42	**2.73**	967.75	3.00	**589.86**	**3.25**	1129.19
RT	12.25	1208.50	**10.00**	**828.38**	11.88	1377.39	2.91	961.72	3.00	**589.86**	3.38	1119.59
TB	12.17	1209.35	**10.00**	**828.38**	**11.50**	1389.22	2.82	980.27	3.00	**589.86**	3.38	1117.44
CR	12.42	1289.95	10.00	885.86	12.38	1455.82	2.91	1135.14	3.00	658.88	3.38	1361.14
PB	12.58	1296.80	10.00	838.01	12.13	1446.20	3.00	1117.70	3.00	589.93	3.38	1360.57
TH	12.33	1238.00	10.00	832.00	12.00	1284.00	3.00	1005.00	3.00	650.00	3.38	1229.00

Average of the best solutions computed by different VRPTW algorithms. Best results are in boldface. RT=Rochat and Taillard (1995), TB= Taillard et al. (1997), CR=Chiang and Russel (1993), PB=Potvin and Bengio (1996), TH= Thangiah et al. (1994)

	Old Best			**New Best**	
Problem	**source**	**vehicles**	**length**	**vehicles**	**length**
r112.dat	RT	10	953.63	**9**	982.140
r201.dat	S	4	1254.09	4	**1253.234**
r202.dat	TB	3	1214.28	3	**1202.529**
r204.dat	S	2	867.33	2	**856.364**
r207.dat	RT	3	814.78	**2**	894.889
r208.dat	RT	2	738.6	2	**726.823**
r209.dat	S	3	923.96	3	**921.659**
r210.dat	S	3	963.37	3	**958.241**
rc202.dat	S	4	1162.8	**3**	1377.089
rc203.dat	S	3	1068.07	3	**1062.301**
rc204.dat	S	3	803.9	3	**798.464**
rc207.dat	S	3	1075.25	3	**1068.855**
rc208.dat	RT	3	833.97	3	**833.401**
tai100a.dat	RT	11	2047.90	11	**2041.336**
tai100c.dat	RT	11	1406.86	11	**1406.202**
tai100d.dat	RT	11	1581.25	11	**1581.244**
tai150b.dat	RT	14	2727.77	14	**2656.474**

New best solution values computed by MACS-VRPTW.
RT=Rochat and Taillard (1995), S = Shaw (1998) TB= Taillard et al. (1997)

AntOptima

From research to applications:

AntRoute: Dynamic fleet optimization for fuel distribution, Pina Petroli SA, Grancia, CH

Fuel distribution

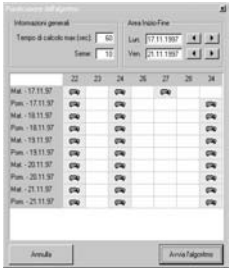
Multiple time windows

Stochastic quantity

Accessibility restrictions

Non homogeneous Vehicle characteristics

- Lorries must return to the depot for the lunch break
- Lorries are equipped with:
  - tanks of different capacities (7500, 11500, 23500 litres)
  - hoses of different diametres (1 ¼ and 2 inches) and length (30, 50, 120 metres)



Half day availability
Half day planning with one week visibility

Service times assumptions

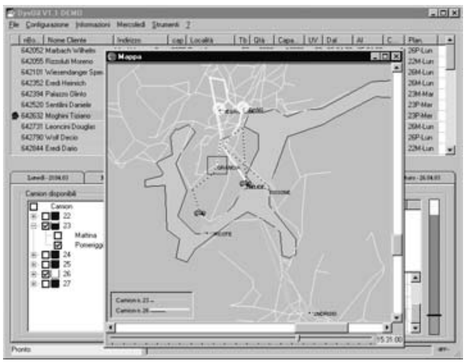
- Travel time between two nodes is computed according to distance, road type and weather conditions
- Customer lookup time: it is a parameter of the customer
- Set-up time: it is computed according to the length of the hose
- Oil delivery time: it is computed according to an approximate equation of the valve installed on the lorry

Minimise the total time required to serve all orders

AntRoute

ANtRoute is a software which helps to:

- browse the orders to be delivered
- examine the constraints imposed by the customer (time windows, accessibility, etc.)
- manage the vehicle database
- enter a manually designed tour
- use an algorithm to compute a solution
- visualise the tours on a map
- reallocate orders to vehicles to accommodate unexpected orders



Dynamic fleet optimization for fuel distribution, Pina Petroli SA, Grancia, CH

Improvement certified at

Pina Petroli SA, Grancia, CH

Computational time PC: 3 minutes
Average improvement: 20%

Ant-Route

IDSIA


Der Spiegel

COMPUTER

Duft der Daten

Auf kürzestem Weg tragen Ameisen das Futter in ihren Bau. Programmierer nutzen jetzt die Tricks der Insekten, um die Abläufe in Fabriken zu optimieren.

Tag für Tag kämpfen sich die Lieferwagen der Firma Pina Petroli die steilen Hänge am Ufer des Luganer Sees empor, um selbst die entlegensten Gehöfte noch mit Brennstoff zu versorgen. Vor allem im Winter aber bleibt zuweilen die Küche kalt: Eine Straße ist verschneit, ein Wagen kaputt.

Nun soll das Fahrten-Management auf ungewöhnliche Weise optimiert werden: mit Hilfe der Ameisen. Das findet zumindest Luca Maria Gambardella, Berater von Pina Petroli und Direktor des Idsia-Instituts für künstliche Intelligenz im schweizerischen Manno: „Ameisen

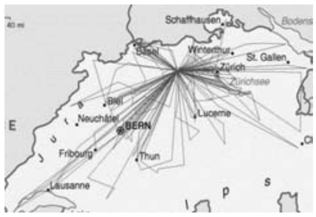
Verkehrsfunk der Ameisen…

Liegt einem Ameisenvolk ein Stein im Weg, so geht zunächst die Hälfte links und die andere Hälfte rechts herum. Beide Trupps hinterlassen eine Duftspur aus Pheromonen, die mit der Zeit verdunstet und schwächer wird.

Auf der kürzeren Route drängeln sich die Tiere stärker. Der dadurch intensivere Geruch

The Suhr distribution problem

- Central Depot
- Non-homogeneous fleet
- Customers accessibility restriction
- Customers time windows



Objectives

1. N. of tours minimization
2. Cost minimization

Cost function = total_km * km_cost + total_time_violation * tv_cost

Non-homogeneous (infinite) fleet of vehicles

- Truck
- Truck + trailer
- Tractor unit + semi-trailer

Remark: All capacities are expressed in pallets.

Other features:

- Embedded lift
- Refrigerated container
- Parking time (constant)
- Service time (variable)
- Trailer hook / unhook time (constant)

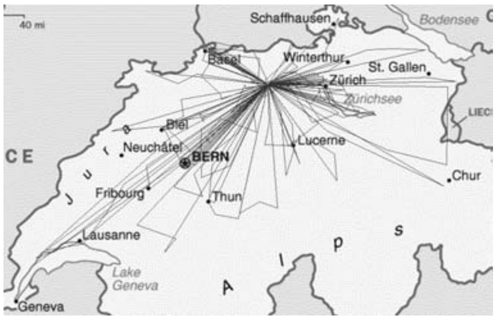
Ant-Route
The first prototype test

Total number of orders	228
Total number of pallets	1736
Type of trucks available	MW+ANH, SS
MW+ANH capacity	35 pallets
SS capacity	33 pallets
MW capacity	17 pallets
Kilometric cost	3.10 fr. / km
Time windows violation cost	75.00 fr. / hour
Time windows width	60 min
Suhr opening - closing time	05:00 - 22:00
Trailer unhooking time	10 min
Trailer hooking time	10 min
Parking time	10 min
Unloading time	90 sec / pallet

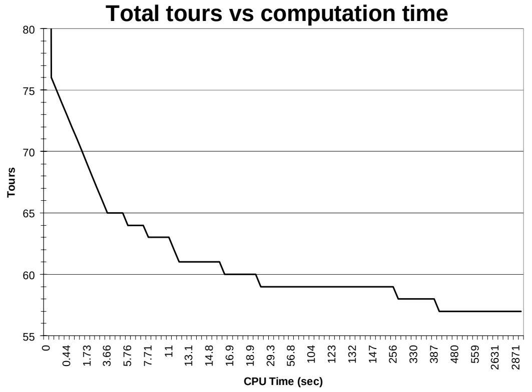
Ant-Route results

	1st disp.	2nd disp.	Ants	Gap (1st disp.)
Total number of tours	59	60	58	**-1**
Number of tours with AHZ	47	43	53	+ 6
Number of tours with SS	11	15	0	- 11
Number of tours with MW SOLO	1	2	5	+ 4
Average truck filling percentage	85.75%	85.50%	88.91%	**+ 3.16%**
Average number of orders per tour	3.881	3.816	3.931	+ 0.05
Average number of pallets per tour	29.424	28.933	29.931	+ 0.507
Total time windows violation time	159h 07m	131h 19m	12h 24m	**- 146h 43m**
Total waiting time	6h 30m	39h 14m	12h 24m	+ 5h 54m
Total delay time	152h 37m	92h 5m	0h 0m	- 152h 37m
Total km	10397 km	10793 km	10579 km	**+ 182 km**
Total cost	44'165 fr.	43'307 fr.	33'725 fr.	**- 10'440 fr.** 23.6%
Solution generation time	4 hours	4 hours	5 min	**- 3h 55m**

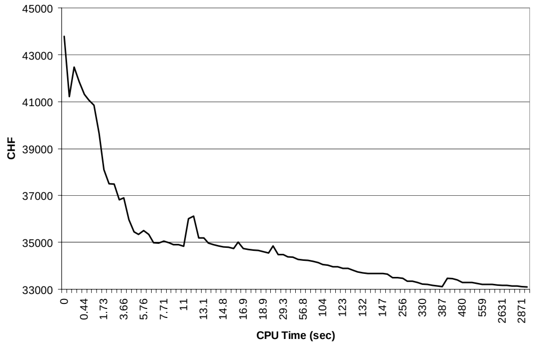
Ant-Route result after 5 minutes



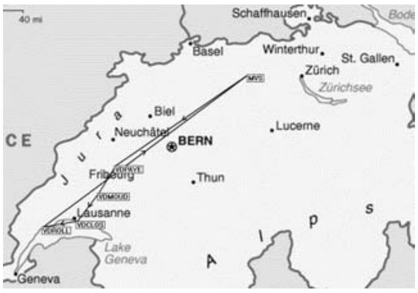
Total tours vs computation time



Total solution cost vs computation time



Dispatcher evaluation: good tours



During the evaluation a dispatcher said "around the depot…, today I learnt something"

AntRoute has been redesign and extended with new (non academic) features:

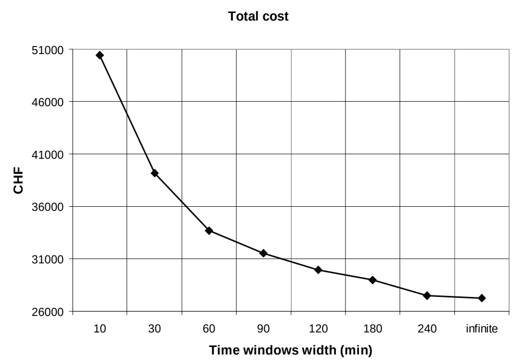
regionalization, pick-up and delivery, internal and external trucks with different costs. Constraints on the number, the position and the presence of customers in the same tour.

Ant Route Results

Main Objective: number of tours minimization

	Number of tours	Tot KM	Km x tour	Loading %	Computation Time
Time windows +- 30 minutes With Distribution areas	-12%	-2,2%	+12%	+13,5%	5 min Vs 4 persons 4 hours
Free Optimization No Time Windows No areas	-21,5%	-14,2%	+10%	+27%	5 min

Ant-Route as a Strategic tool



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Ant-Route as a Strategic tool

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Ant-Route: about the algorithm…

Foundations

- MACS-VRPTW (1999, Gambardella, Taillard, Agazzi)
- Two colonies of ants
- Constructive phase (exploration & exploitation) + Local search

Extensions & Adaptations

- Vehicle choice at the start of each tour (pheromone based)
- Trailer hooking / unhooking management
- Constrained tours shape (to cope with dispatchers tastes…)
- Area structure management
- Starting time of each tour
- Vehicles usage optimization

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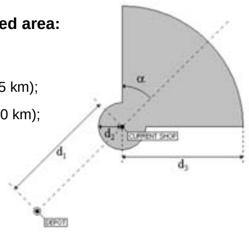
Constrained tours shape

The next shop must lie inside the grayed area:

- d_1 is the **distance from the depot**;
- d_2 is the **free distance** to the next shop (25 km);
- d_3 is the **max distance** to the next shop (60 km);
- α is the **cone semi angle**;
- α_{min} is the **mimimum** semi-angle (60°);
- d_α is the distance from the depot where α becomes α_{min} (140 km).



$$\begin{cases} \alpha = 180^o + \left(\alpha_{\min} - 180^o\right)\dfrac{d_1}{d_\alpha}, & d_1 \le d_\alpha \\ \alpha = \alpha_{\min}, & d_1 > d_\alpha \end{cases}$$

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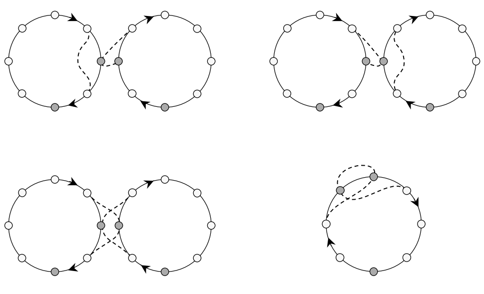
Local search exchanges



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AntOptima
we speed up your business

NUMBER 1 LOGISTICS GROUP

AntRoute

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Number1 Logistics Group Italia

Number1 is the largest Italian logistic operator (Barilla group)

Moves goods from factories to stores

700/1000 vehicles x day

No own fleet but all external trucks

Multiple starting points

Pick-up and delivery along Italy

The distribution problem of Number1

- Pick-up & Delivery: there is not a central depot
- Every order has a source point and a destination point
- Every point of the distribution network has a time window
- Every point of the network has a constant service time
- Heterogeneous point typology: providers, depots, clients
- Homogeneous fleet of vehicles

Objective:

Maximization of the average tours efficiency.

This should implicitly have as a side effect the minimization of the number of tours and of the total km.

Homogeneous (infinite) fleet of vehicles

Tractor unit + semi-trailer

- Each vehicle has two capacities: Nominal and Maximum
- Each capacity has three dimensions: pallets, kg, m^3

Unit of measurement	Nominal capacity	
pallets	33	
kg	27000	
m^3	76	

Constraints

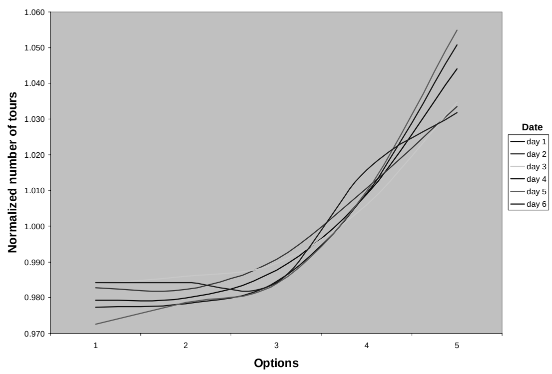
1. Respect of the time windows at each distribution point
2. Respect of the max. capacities of the vehicles
3. Limit the maximum number of points per tour
4. Limit the maximum number of clients per tour
5. Pick-ups and deliveries regionalization
6. At most 9 hours of travel per day
7. Order groups cannot be split into different tours

Feasibility study

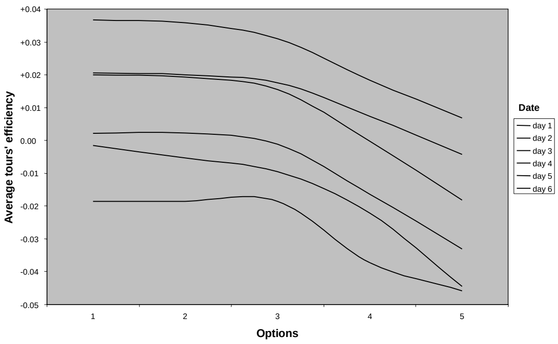
Different constraints scenarios have been evaluated

Option	Max points per tour	Max clients per tour	Use pick-up regions	Use delivery regions
1	NO	NO	NO	NO
2	NO	YES	NO	NO
3	YES	YES	NO	NO
4	YES	YES	YES	NO

Second feasibility study



Second feasibility study



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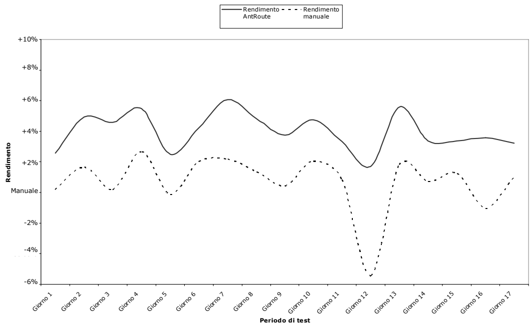
Performances Planner VS AntRoute



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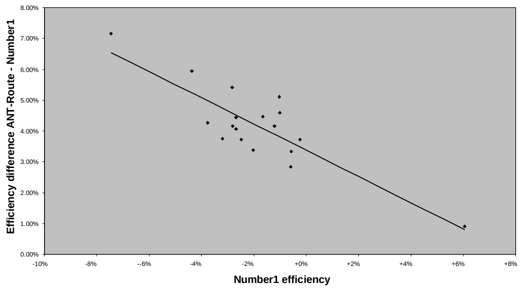
Final version acceptance test

Correlation between performance gain and problem difficulty



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ANT-Route: Algorithm description

Same philosophy as in MACS-VRPTW but…

- Only one colony of ants (efficiency maximization)
- Each order involves two physical points (source and destination): this heavily increases the search space.
- The algorithm consists of:
  - a constructive phase using a LIFO policy;
  - a first level local search exchanging orders between different tours and preserving the LIFO structure;
  - a second level local search exchanging points within each tour individually.

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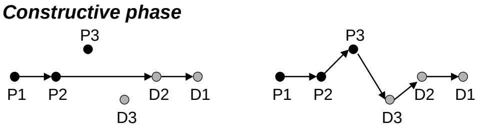
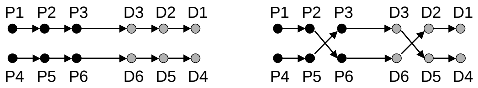
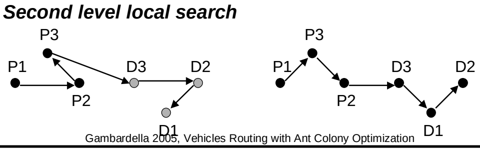
Constructive phase



First level local search



Second level local search



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Number1 Logistics Group Italia

AntRoute is fully integrated in the operative process

Continuous optimization of new orders

5 minutes running time for the optimization of 700-1000 tours

Performance improvement from 2 to 4-5%.

Performance Parma-Veneto from 86.5% to 89.9%.

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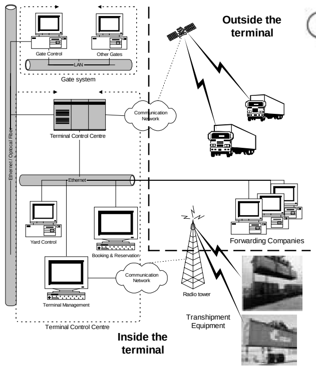
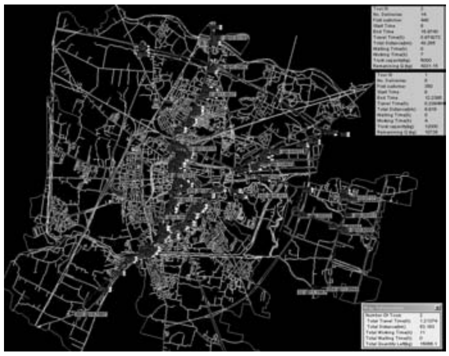


MOSCA EU 5
(2001-2004)

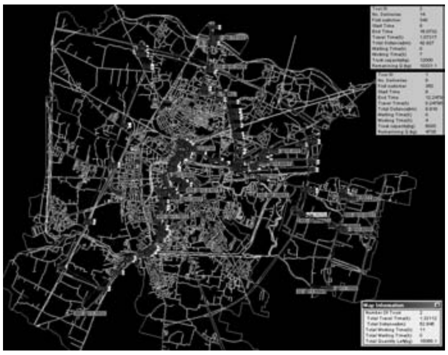
On line urban distribution with dynamic traffic information and on-line orders

IT, DE, CH, UK

Planning under different traffic conditions



Donati, A.V., Montemanni R., Gambardella, L.M. and Rizzoli, A.E. Integration of a robust shortest path algorithm with a time dependent vehicle routing model and applications. Proceedings of CIMSA 2003 - International Symposium on Computational Intelligence for Measurement Systems and Applications, Lugano, Switzerland, pages 26-31, 29-31 July 2003.



Stochastic VRP problems

FN SNF
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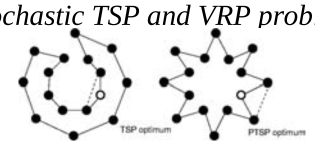
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

Extension of the ACO approach to stochastic TSP and VRP problems



Bianchi L., Gambardella L. M., and Dorigo M. Solving the homogeneous probabilistic traveling salesman problem by the ACO metaheuristic. In M. Dorigo, G. Di Caro, and M. Sampels, editors, Proceedings of ANTS 2002 - Third International Workshop on Ant Algorithms, Lecture Notes in Computer Science. Springer Verlag, Berlin, Germany, 2002.

Conclusions

Complex problems require innovative algorithms.

Research community is ready to provide new solutions.

The goal is the "few minutes optimisation".

This allows also strategic and on line reasoning.

Thank you for your attention