Livestock Collection

Johan Oppen
Molde University College

Outline

- Motivation.
- The Livestock Collection Problem.
  - Models.
- Solution methods.
  - Tabu Search.
  - Column generation
- Computational results.
- Conclusions.

Motivation

- In this case, motivation is the easy part.
- The industry wants an automatic planning system for transportation of animals for slaughter.
  - Today, the routes are planned manually.
  - The industry thinks there is a potential for savings.
  - Currently available software seems to be unable to handle this problem in a satisfactory way.
- Find an academic partner and do a research project!

Motivation

- Research project 2003-2008: ”Transportation of live animals – reduced transportation costs, good animal welfare and first-class meat quality”.
  - Animalia (The Norwegian Meat Research Center).
    - Project administration.
    - Animal welfare aspects.
  - Molde University College.
    - Modelling, solution methods.
    - Four master theses, one PhD.
  - Two meat companies: Nortura (Gilde) and Fatland.
    - Problem description, test data.

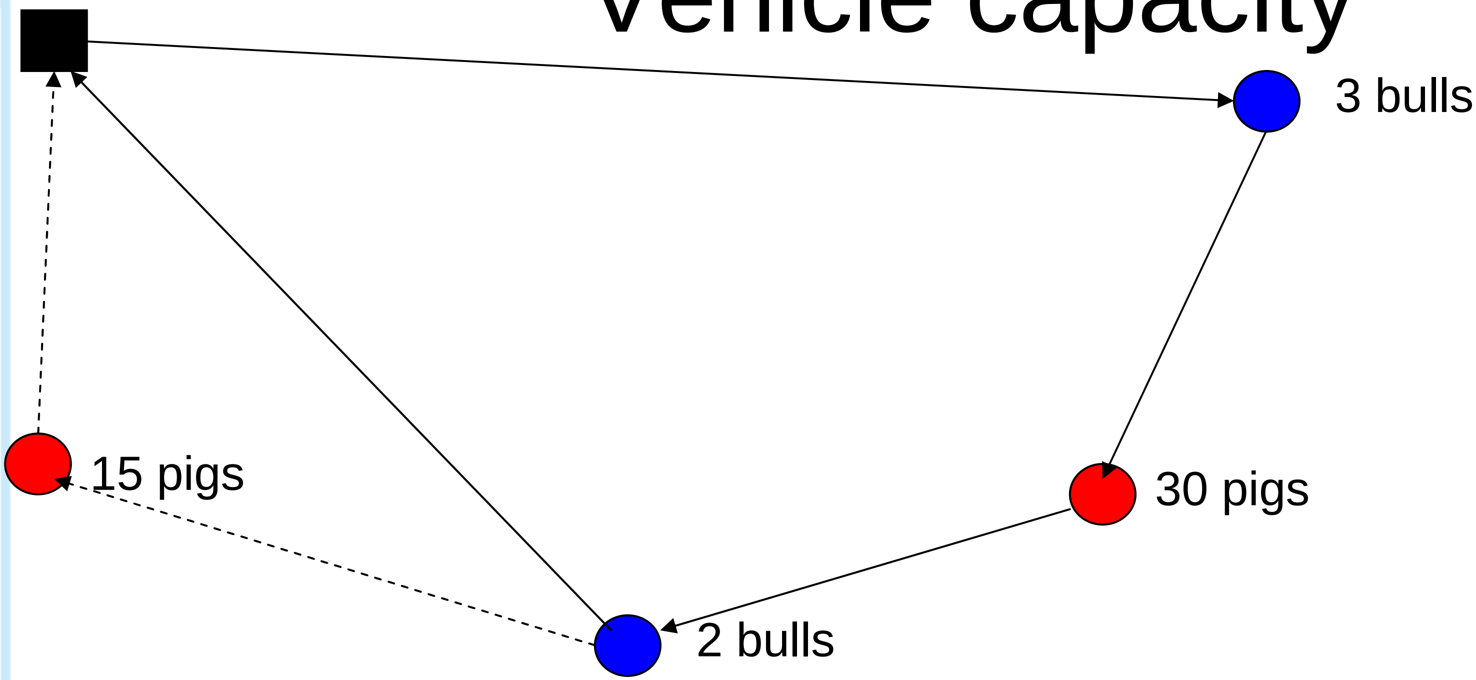
Real-world problems

- When we want to solve problems from the real world, we have to be careful.
  - All important features of the problem must be included, even if our model gets large and ugly.
  - If the model is not close enough to the real problem, we may solve the wrong problem.
  - Solutions to the wrong problem is of no or very limited value.
  - We may have to accept that optimal solutions are impossible to find.
  - Heuristics may have to do the job.

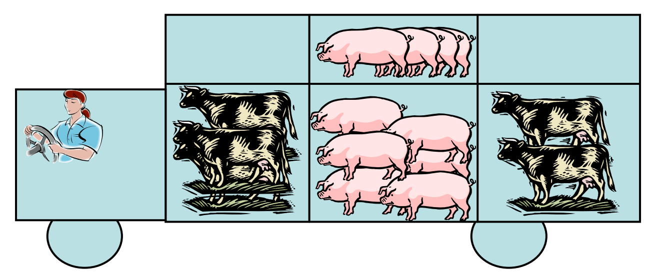
The Livestock Collection Problem

- A rich VRP with inventory/production constraints.
  - Live animals are different from most other types of load.
  - Rules to support animal welfare.
  - Trade-off between vehicle capacity and route length becomes an issue.
  - Inventory constraints are added.
- VRP constraints on the routes.
  - Duration, mix of animal types, capacity, precedence.
- Inventory constraints.
  - The set of routes must fit to the production (slaughter) plan and inventory capacity at the slaughterhouse.
- Time horizon typically one week.

Vehicle capacity

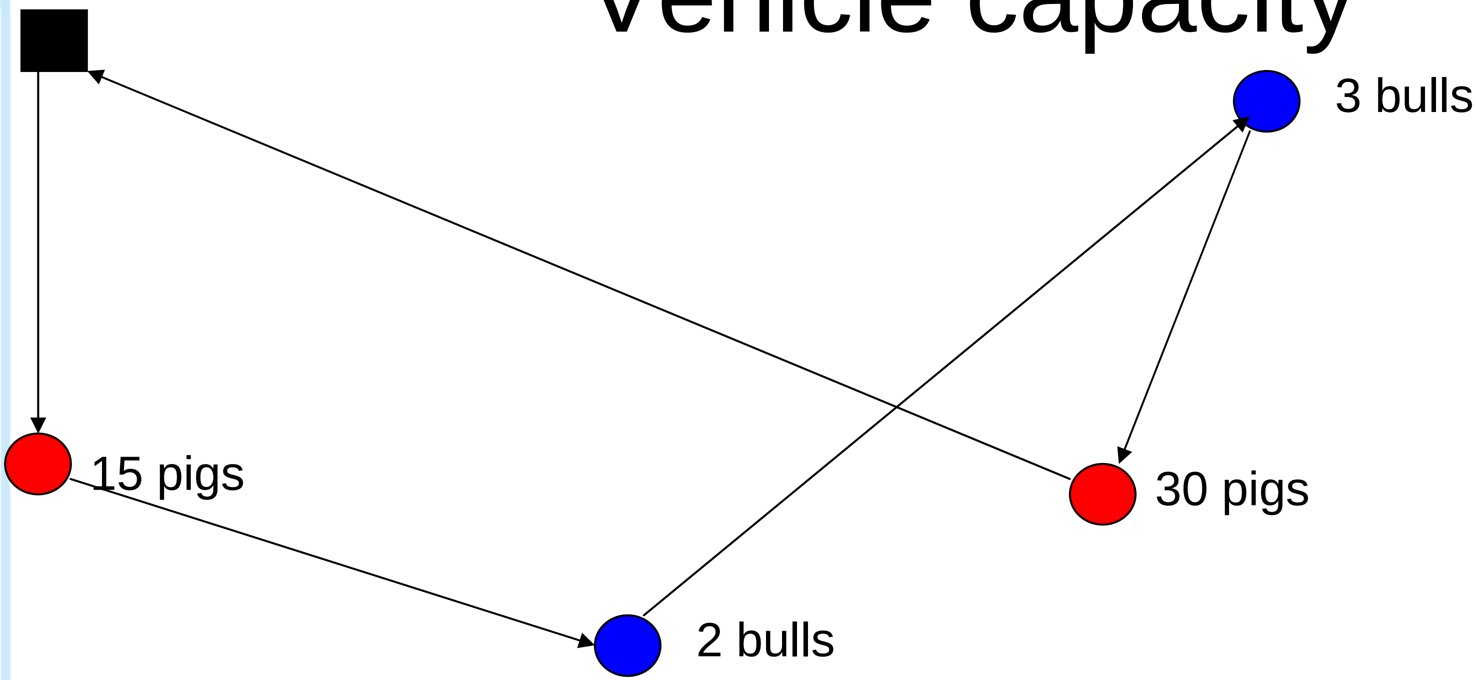


A tour with minimal distance is not always the best.

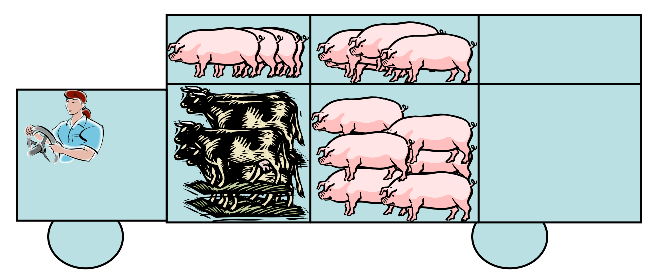


The vehicle can take pigs in 2 tiers, or pigs on top of bulls.

Vehicle capacity



A longer tour may give more capacity.



The vehicle can take pigs in 2 tiers, or pigs on top of bulls.

Models

- A mathematical model for the current version of the LCP can be written down in about 40 lines.
- It is large and ugly, or it is very nice, depending on what you want to do.
  - If you want to solve real-world instances to optimality, forget it.
  - If you want to use heuristics, it is a nice problem.
- A real-world instance will have millions of binary variables and non-linear constraints.

Models

- The LP relaxation of this type of model is typically 10 – 20% below the optimal IP solution.
- HUGE integrality gap.
- Simpler model solved to optimality with CPLEX for 7 orders.
  - Same type of model, standard VRP model with flow variables on the arcs.
  - Only one animal type, difficulties with mixing, loading sequence and computing capacity disappear.
  - Time periods during the day increases the model size.
  - No solutions with 8 orders.

Alternative formulation

- Apply Danzig-Wolfe decomposition and reformulate the original model into.
  - Master problem: set covering model based on *duties,* with global inventory constraints added.
    - A duty is one day's work for one vehicle.
    - The master problem has only a few rows.
  - Subproblems: Resource constrained shortest path problems.
    - All the routing constraints are put here, subproblems are solved by dynamic programming rather than by CPLEX.
    - Trips are short, typically 2-5 stops.
  - The LP relaxation is now typically < 2%.
  - SMALL integrality gap.
  - But there are quite a few variables ...

Solution methods

- Tabu Search heuristic developed.
- Basic ideas: generate a starting solution, move from one solution to the next by doing small changes to the current solution.
  - Avoid getting stuck in local optima.
  - Guide the search into unexplored parts of the solution space.
  - Allow for intermediate infeasible solutions.
    - Dynamic penalties to force the search back into the feasible region from time to time.
  - Special attention needed to handle inventory constraints, as these are global.

Solution methods

- Exact method based on column generation and the set covering model.
- Basic idea in column generation: solve the LP relaxation of the master problem with only a small number of variables (*restricted* master problem), generate and add new variables (columns) iteratively until the master problem is optimal.
  - Optimality condition: When no more columns with negative reduced cost can be found in the subproblems, the optimal solution for the restricted master problem is also optimal for the master problem.
- Because we are looking for a solution to an integer problem, apply Branch & Bound and solve the master by column generation in each node of the B&B tree.

Column generation

- What are the main difficulties?
- Master problem:
  - We have added inventory constraints to the standard VRP model.
- Subproblems:
  - We have no time windows, so it is possible to go almost anywhere when we generate paths.
  - Domination is difficult, especially with respect to capacity.
- Branch & Bound:
  - There is a lot of symmetry.
    - Days are almost the same.
    - Vehicles have almost the same capacity.
  - Branching decisions are important, we have to try different strategies.

Results

- Small instances with up to 25 customers solved to optimality in reasonable time.
  - Solution time varies a lot.
  - More constrained instances are easier.
- For real-world instances, Tabu Search seems to work well.
  - We do not have much to compare with in terms of alternative heuristics.
  - We seem to outperform manual solutions by at least 10%.
  - Simulated Annealing seems to perform poorer than Tabu Search.

Results – column generation

Instance	Solution time	Nodes explored	Root node LB	Objective value	Gap
n20_v3_a	10 min	291	1860,37	1902,64	2,3%
n20_v3_c	8 sec	7	2566,93	2576,49	0,4%
n20_v3_d	33 sec	39	2543,11	2576,49	1,3%
n23_v3_a	80 min	1	1904,83	1904,83	0%
n24_v3_a	20 hours	1	1923,17	1923,17	0%
n25_v3_a	9 min	111	2054,52	2067,83	0,6%
n25_v3_b	7 min	297	1941,20	1973,55	1,7%
n26_v3_a	2 h 22 min	236	2054,52	2073,47	0,9%
n26_v3_b	78 hours*	5 174*	2082,01	2148,90*	3,2%*

What to do next

- The model is still (and will always be) incomplete.
- We would like to add:
  - Time windows, but we need more data.
  - Ferries in the road network, to compute travel time and travel cost more correctly.
  - Multiple depots.
    - Shared vehicle fleet and simultaneous planning of collection to multiple slaughterhouses.
  - Co-ordinated planning of delivery of live animals and collection of animals for slaughter.

What to do next

- New research project:
  - Nortura, Transvision, Animalia and Molde College.
  - Goal: Do more research and implement results in Transvision Livestock Planner.
  - 2 years, total costs ca. 4 mill. NOK.
  - We have applied for funding and hope for success, we will know by June 18.

Finally

- Thank you for your attention!