Enhanced Decision Making with Black-Box Optimization

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Workshop on Locational Analysis and Related Problems
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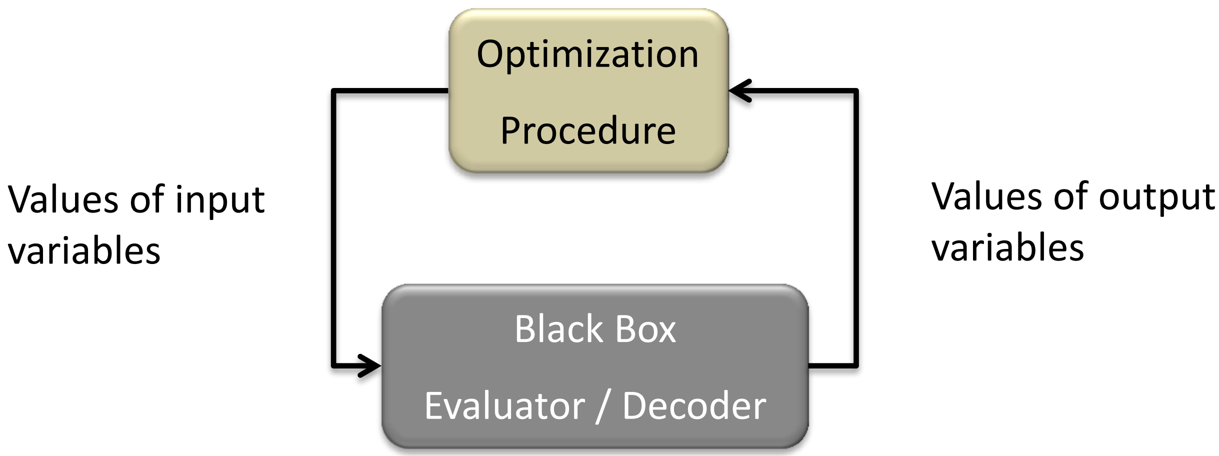
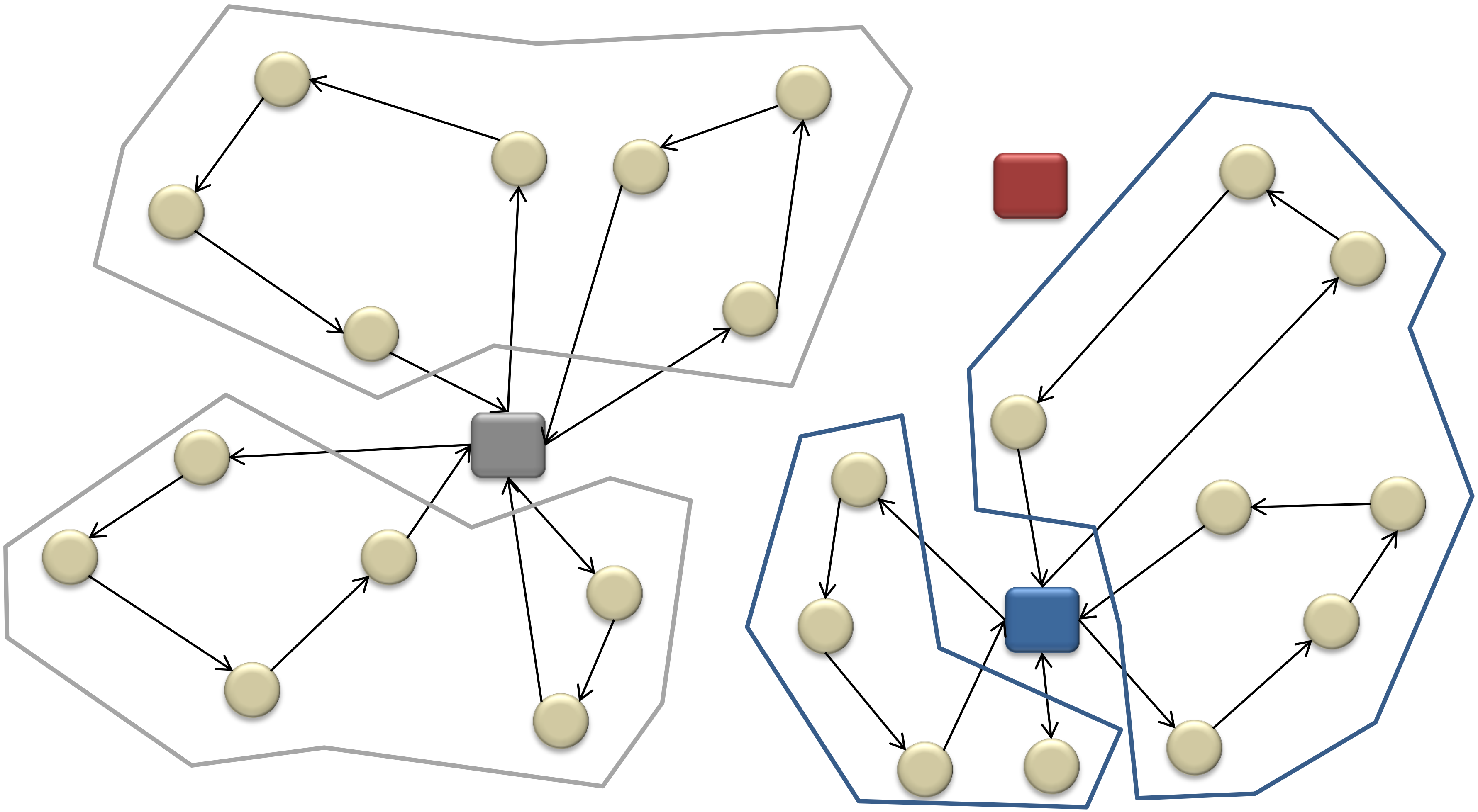
Black Box Optimization



LRSP: Location, Routing and Scheduling Problem

- Objective
  - minimize the total fixed and operating costs associated with facilities and vehicles
- Decisions
  - assignment of customers to facilities
  - set of vehicle routes from facilities to customers
  - assignment of routes to vehicles
- Constraints
  - Capacity (facilities and vehicles)
  - Time (vehicles)

Graphical Representation of a LRSP Solution



A Mathematical Model

Zeliha Akça (2010) “Integrated Location, Routing and Scheduling Problems: Models and Algorithms,” PhD Thesis.

$$\text{Min} \quad \sum_{j \in J} C_j^F t_j + C^V \sum_{h \in H} v_h + C^O \sum_{h \in H} \sum_{(i,k) \in A} T_{ik} x_{ikh}$$

$$
\begin{aligned}
\text{s.t.} \quad & \sum_{k \in N} x_{ikh} - \sum_{k \in N} x_{kih} = 0 && \forall i \in N, h \in H, \\
& \sum_{h \in H} \sum_{k \in N} x_{ikh} = 1 && \forall i \in I, \\
& \sum_{h \in H_j} \sum_{k \in I} y_{jkh} - L_j^F t_j \leq 0 && \forall j \in J, \\
& y_{ikh} - L^V x_{ikh} \leq 0 && \forall (i,k) \in A, h \in H, \\
& \sum_{k \in N} y_{ikh} - \sum_{k \in N} y_{kih} + D_i \sum_{k \in N} x_{ikh} = 0 && \forall i \in I, h \in H, \\
& \sum_{(i,k) \in A} T_{ik} x_{ikh} - L^T v_h \leq 0 && \forall h \in H,
\end{aligned}
$$

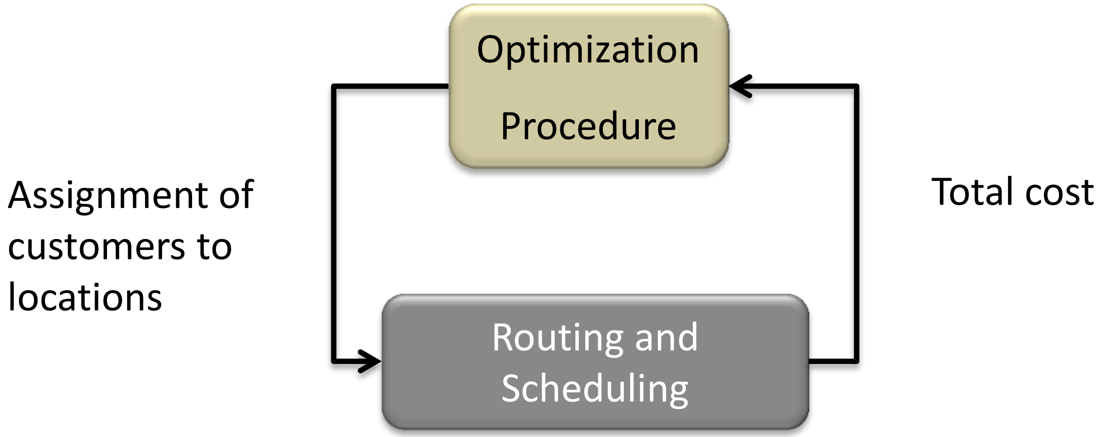
Routing

$$
\left\{
\begin{aligned}
& x_{jkh} = 0 && \forall j \in J, k \in N, h \in H_t, t \in J \backslash \{j\} \\
& x_{ikh} \in \{0,1\} && \forall (i,k) \in A, h \in H, \\
& y_{ikh} \geq 0 && \forall (i,k) \in A, h \in H,
\end{aligned}
\right.
$$

Facility selection $\quad t_j \in \{0,1\} \quad \forall j \in J,$ and

Vehicle selection $\quad v_h \in \{0,1\} \quad \forall h \in H.$

LRSP: Black Box Approach



Solution Representation

Binary (1 = customer assigned to facility):

$$\underbrace{\boxed{1}\boxed{0}\boxed{1}\boxed{1}\boxed{0}\boxed{.}\boxed{.}\boxed{.}\boxed{.}\boxed{0}\boxed{0}}_{\text{Customers} \times \text{Locations}}$$

Discrete (number of facility):

$$\underbrace{\boxed{4}\boxed{2}\boxed{2}\boxed{1}\boxed{1}\boxed{.}\boxed{.}\boxed{3}}_{\text{Customers}}$$

Size of the Solution Space

- Consider a problem with 5 customers and 2 facilities
- Binary representation
  - Number of binary variables = $5 \times 2 = 10$
  - Number of solutions = $2^{10} = 1{,}024$
- Discrete representation
  - Number of discrete variables = 5
  - Number of solutions = $2^5 = 32$

Solution Space for 5 Customers and 2 Facilities

Solution	C1	C2	C3	C4	C5
1	1	1	1	1	1
2	1	1	1	1	2
3	1	1	1	2	1
4	1	1	1	2	2
5	1	1	2	1	1
6	1	1	2	1	2
7	1	1	2	2	1
8	1	1	2	2	2
9	1	2	1	1	1
10	1	2	1	1	2
11	1	2	1	2	1
12	1	2	1	2	2
13	1	2	2	1	1
14	1	2	2	1	2
15	1	2	2	2	1
16	1	2	2	2	2
17	2	1	1	1	1
18	2	1	1	1	2
19	2	1	1	2	1
20	2	1	1	2	2
21	2	1	2	1	1
22	2	1	2	1	2
23	2	1	2	2	1
24	2	1	2	2	2
25	2	2	1	1	1
26	2	2	1	1	2
27	2	2	1	2	1
28	2	2	1	2	2
29	2	2	2	1	1
30	2	2	2	1	2
31	2	2	2	2	1
32	2	2	2	2	2

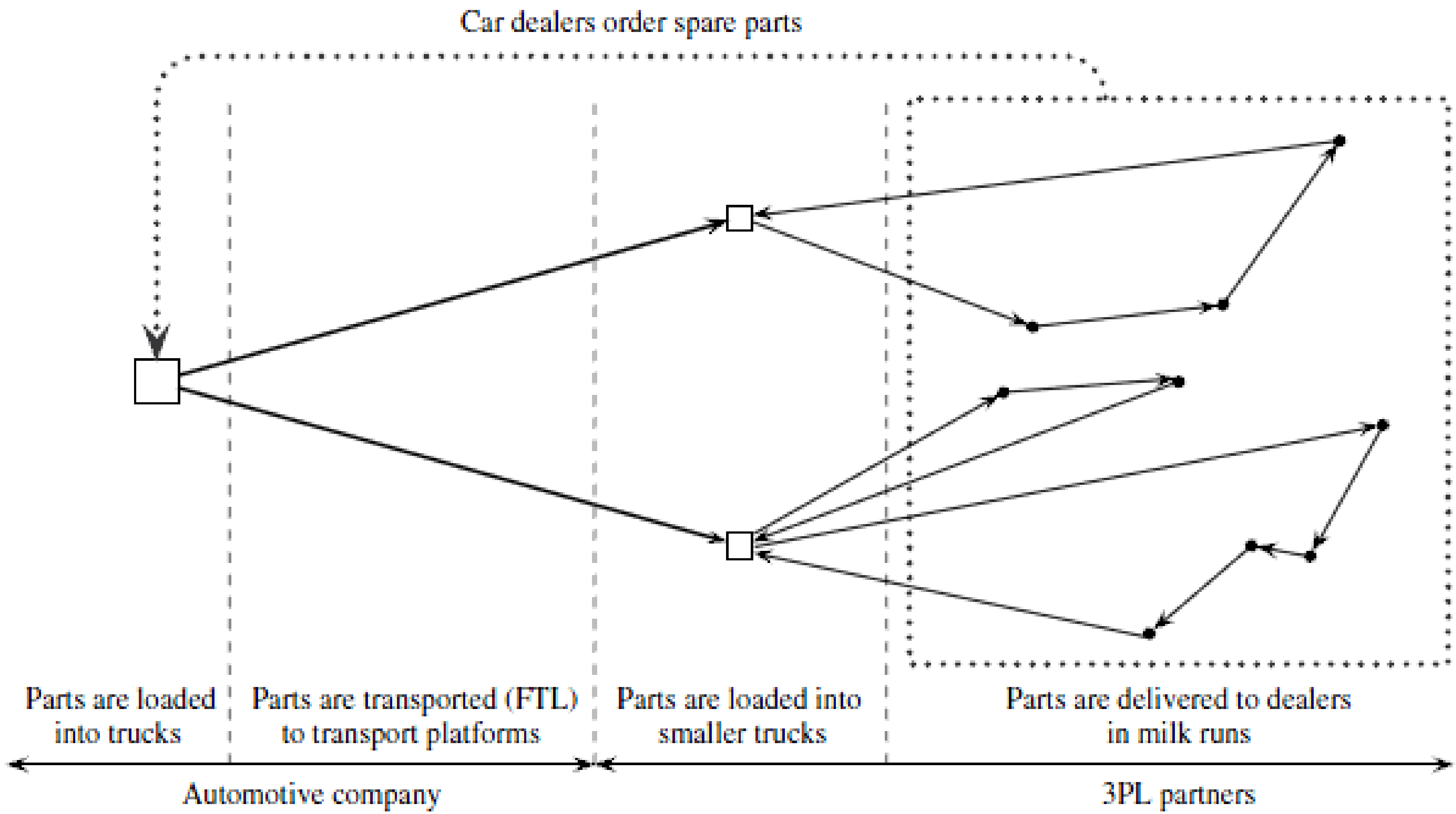
Supporting 3PL Decisions in the Automotive Industry

Schittekat, P. and K. Sörensen (2009) "Supporting 3PL Decisions in the Automotive Industry by Generating Diverse Solutions to a Large-Scale Location-Routing Problem," *Operations Research*, vol. 57, no. 5, pp. 1058-1067.

Problem Setting

- For the distribution of spare parts to car dealers, many automotive companies (e.g., Toyota) use a transport network of intermediate hubs or transport platforms, operated by a set of third-party logistics (3PL) partners
- A tactical optimization problem consists of the selection of 3PL providers and transport platforms in order to minimize cost and achieve a desired service level

Delivery of Spare Parts to Car Dealers



Problem Complexity

- Toyota must determine whether the price structure proposed by a potential 3PL provider is reasonable
- There is uncertainty with respect to the quality of service of 3PL providers
- It is difficult to estimate the total network cost without accounting for operational detail

Decision Support System

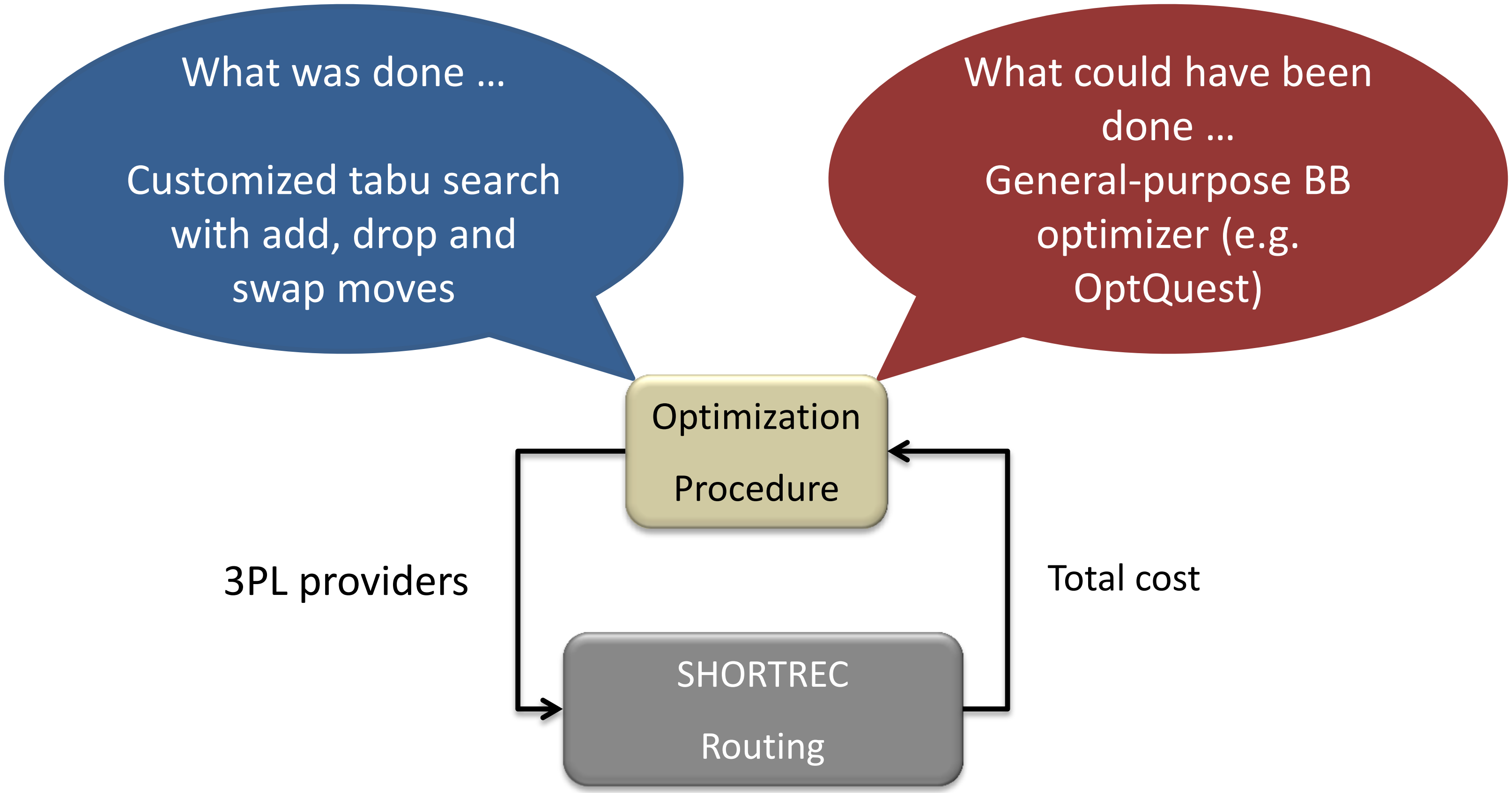
- A solution to the problem consists of a set of 3PL providers
- The merit of a solution is assessed by its total cost
- Solutions must satisfy a desired service level
- Instead of a single solution, the system must provide a set of "structurally diverse" solutions

Location-Routing Problem

1. Selecting 3PL providers and associated transport platforms to use

2. Determining routes to visit the car dealers from the selected transport platforms

Black Box View



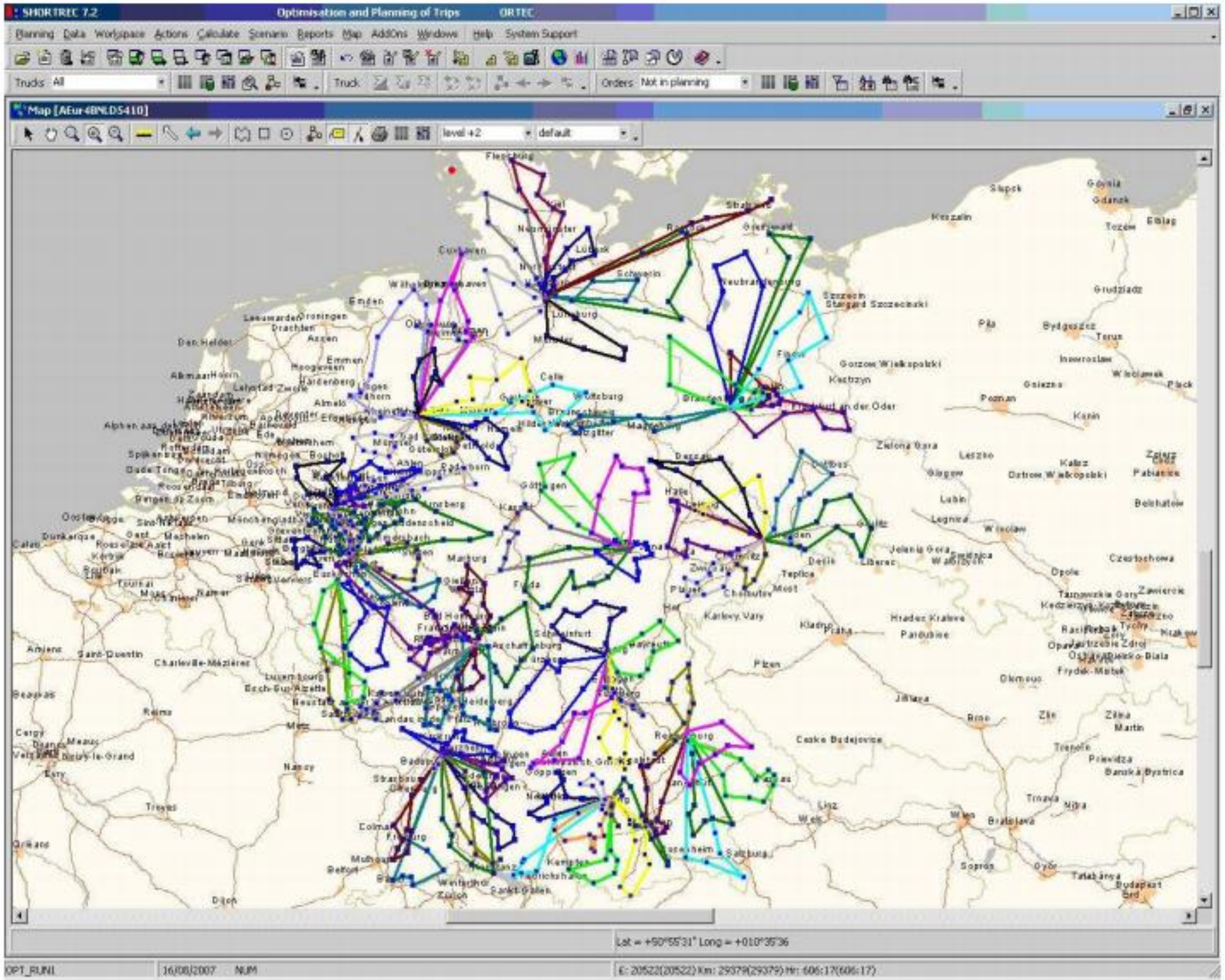
Summary of Results

Table 1. Summary results.

#	Cost (% of current)	N	Avg. Hamming distance
1	91.76	17	8.2
2	93.51	21	9.8
3	93.57	19	11.1
4	94.23	22	9.8
5	94.68	17	7.8
6	94.80	18	13.6
7	95.43	19	7.3
8	95.81	21	9.3
9	95.83	24	12.0
10	100	14	10.7

Current Solution

Best Solution



More Applications of the BB Approach

- Periodic Vehicle Loading Problem
  - Delgado, C., M. Laguna and J. Pacheco (2005) "Minimizing Labor Requirements in a Periodic Vehicle Loading Problem," *Computational Optimization and Applications,* vol. 32, pp. 299-320.
- Periodic Vehicle Routing Problem
  - Alegre, J., M. Laguna and J. Pacheco (2007) "Optimizing the Periodic Pick-up of Raw Materials for a Manufacturer of Auto Parts," *European Journal of Operational Research,* vol. 179, no. 3, pp. 736-746.
- Crane Scheduling
  - OptTek project

Periodic Vehicle Loading Problem

- On each given day, a manufacturer must have enough workers to load customer vehicles that arrive at the manufacturer's facility to pick up orders. Customers need to pick up orders with a desired frequency (e.g., one pickup every 4 workdays)

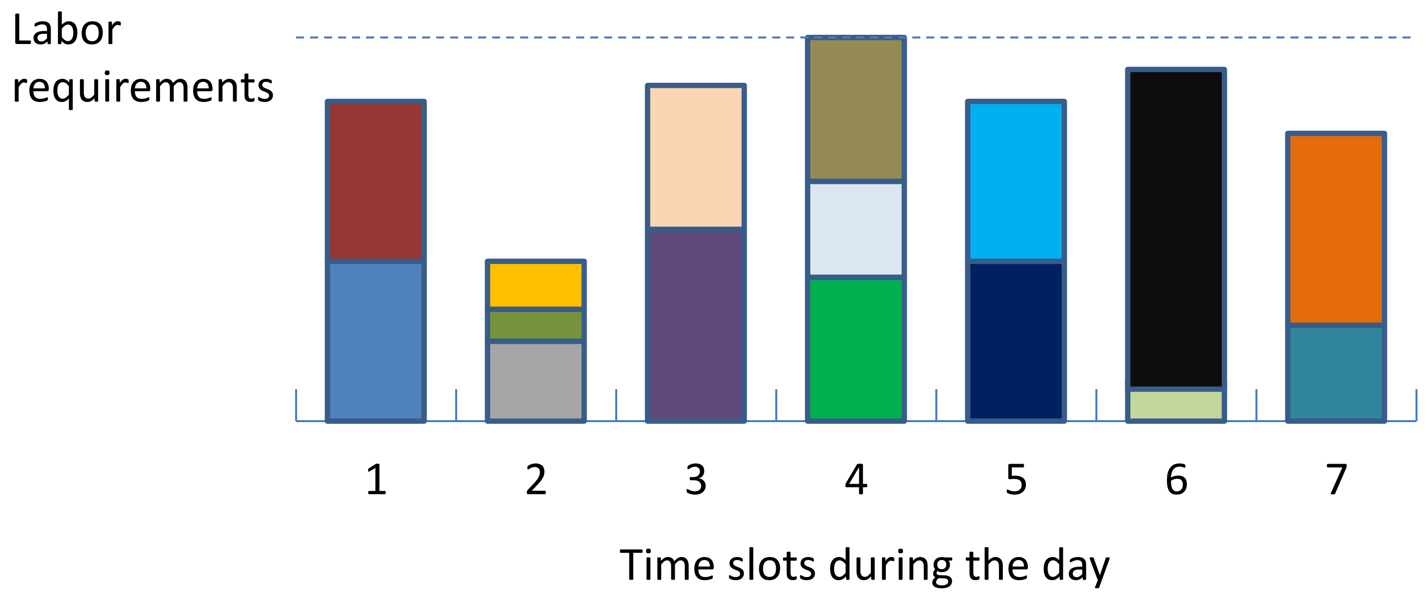
- Calendars in a 20-day planning horizon for 1 pickup every four days:
  - {1, 5, 9, 13, and 17}
  - {2, 6, 10, 14, and 18}
  - {3, 7, 11, 15, and 19}
  - {4, 8, 12, 16, and 20}

Two Subproblems

1. Assigning each customer to a set of days in the planning horizon such that the frequency requirements are satisfied. That is, the sub-problem consists of assigning each customer to one of its feasible pickup calendars.

2. Assigning each customer to a time slot within each day such that the labor requirements are minimized. (Customers cannot be assigned to more than one time slot because they are not willing to visit the supplier's facility more than once in a single day.)

Time Slot Assignment

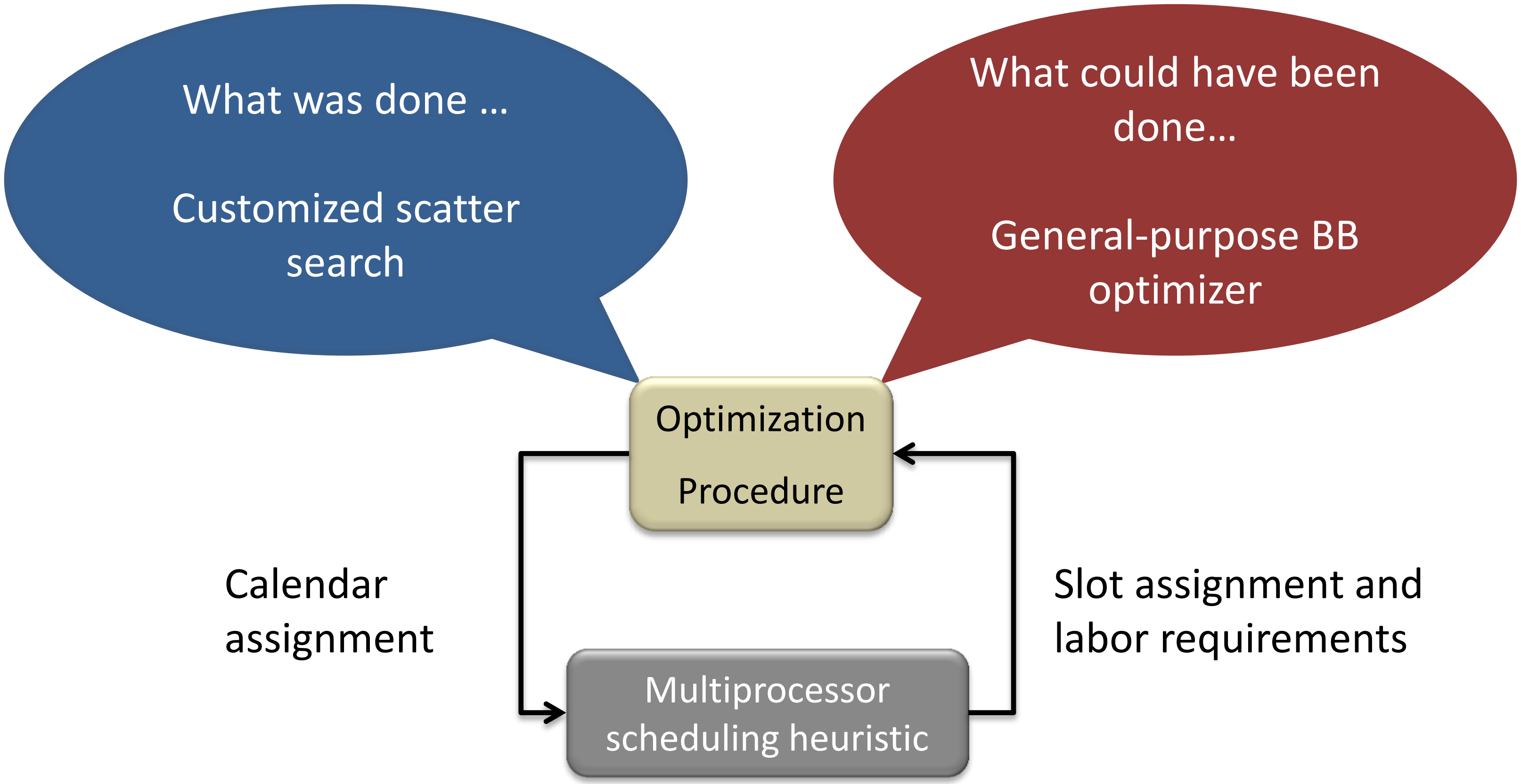


* Each block represents the labor required to load a customer's order

Time Slot Assignment

- The problem is known in the literature as …
  - Multiprocessor scheduling problem
  - Bin packing problem

Black Box View



Periodic Vehicle Routing Problem

- A manufacturer of parts for automobiles in the north of Spain must pick up different raw materials from suppliers that are geographically dispersed.
- The frequency by which raw materials need to be picked up is determined by the production schedules of both the manufacturer and its suppliers.

Two Subproblems

1. Assigning each raw material order to a set of days in the planning horizon such that the frequency requirements are satisfied. That is, the decision problem consists of assigning each raw material to one of its feasible pickup calendars.

2. Designing the daily routes in such a way that their collective cost is minimized. That is, for each day in the planning horizon cost-minimizing vehicle routes must be configured

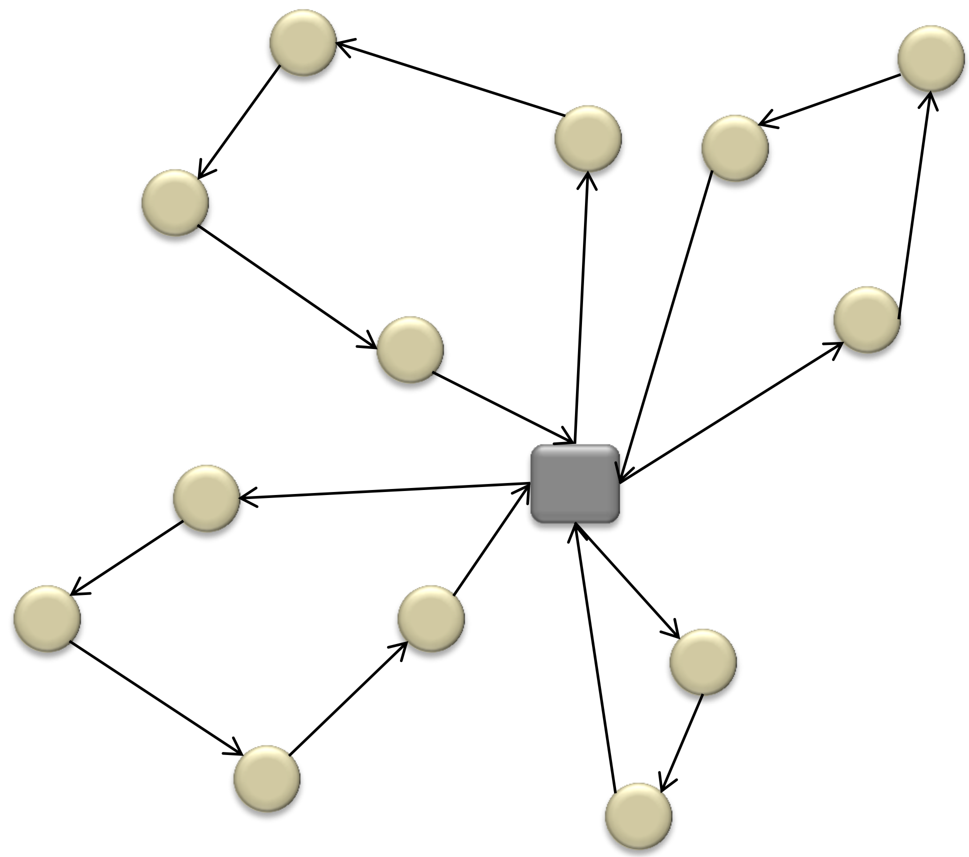
Single Day VRP

Given

- Customers
- Demand
- Vehicles
- Capacities

Find

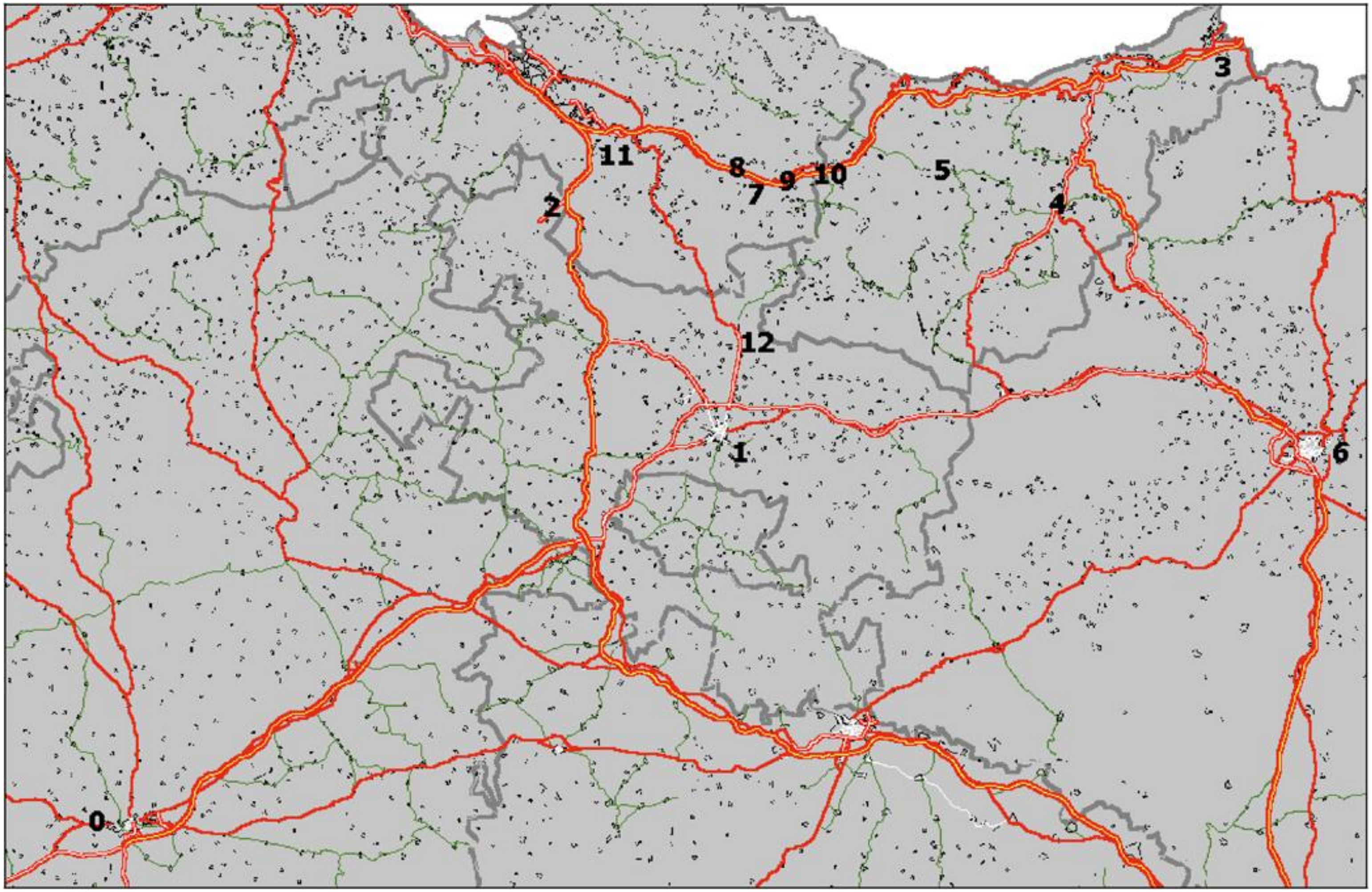
- Routes
- Cost



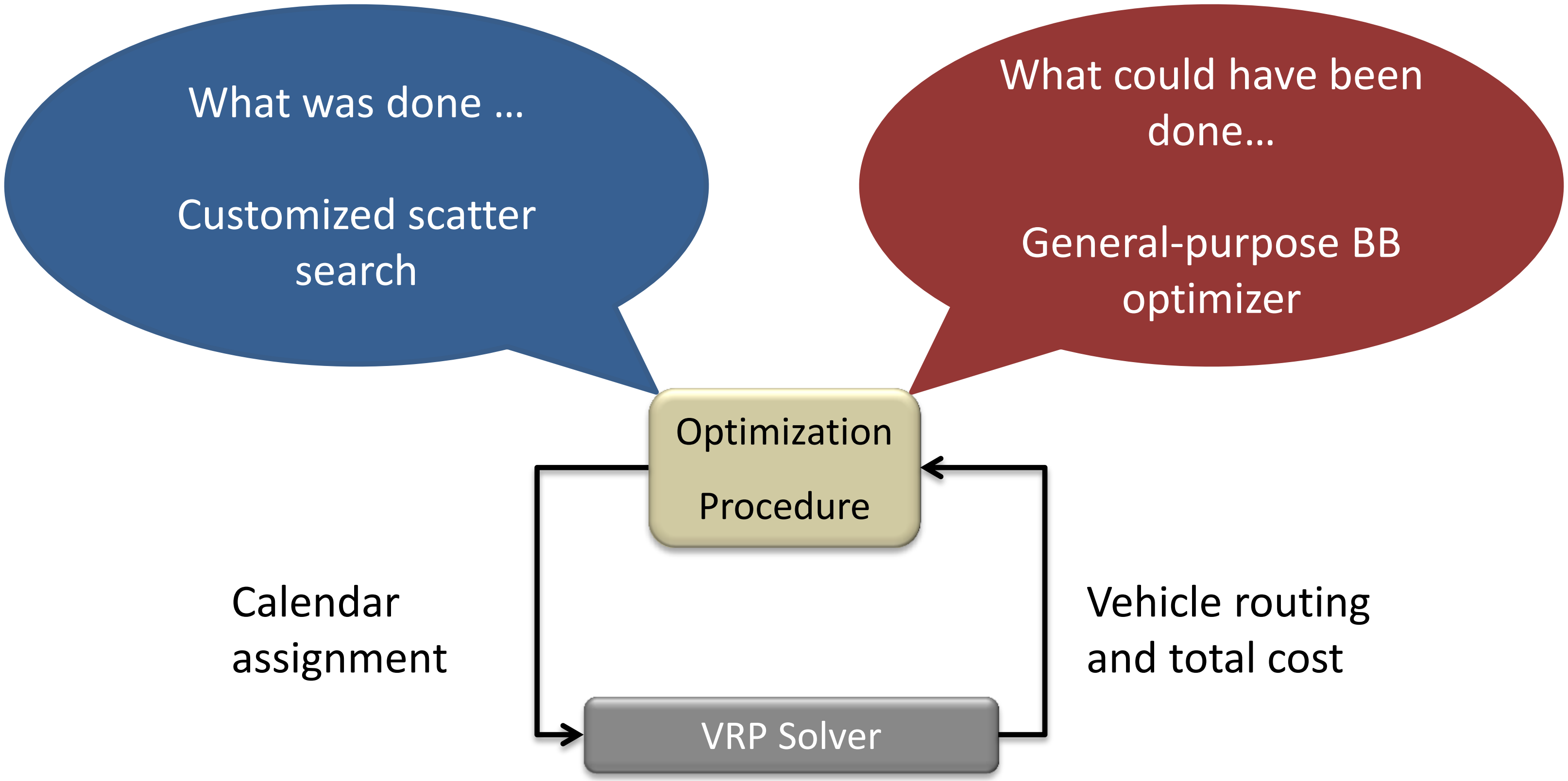
Calendar Assignment vs. Routing

- The periodic vehicle routing problem (PVRP) has been addressed in the literature
- The emphasis, however, has been on the VRP problem
- The current context is characterized by longer planning horizons and a variety of calendars with somewhat simple VRP’s to solve for each day

Typical Geography for a single VRP



Black Box View



Crane Scheduling

- OptTek Systems was hired to provide an optimization procedure for scheduling tasks for a crane in a rail yard.

- The procedure was designed to be embedded in OASIS

OASIS

OASIS is a comprehensive decision support system that provides real time status of intermodal rail-yard operations.

Opportunity

- Currently, crane operators are provided visibility of their available work in a graphical and textual format where the textual list is ordered by dwell time of street drivers

- A prescriptive work order solution is desirable where the next n moves are chosen based on a given objective function.

Wide-span Crane Scheduling

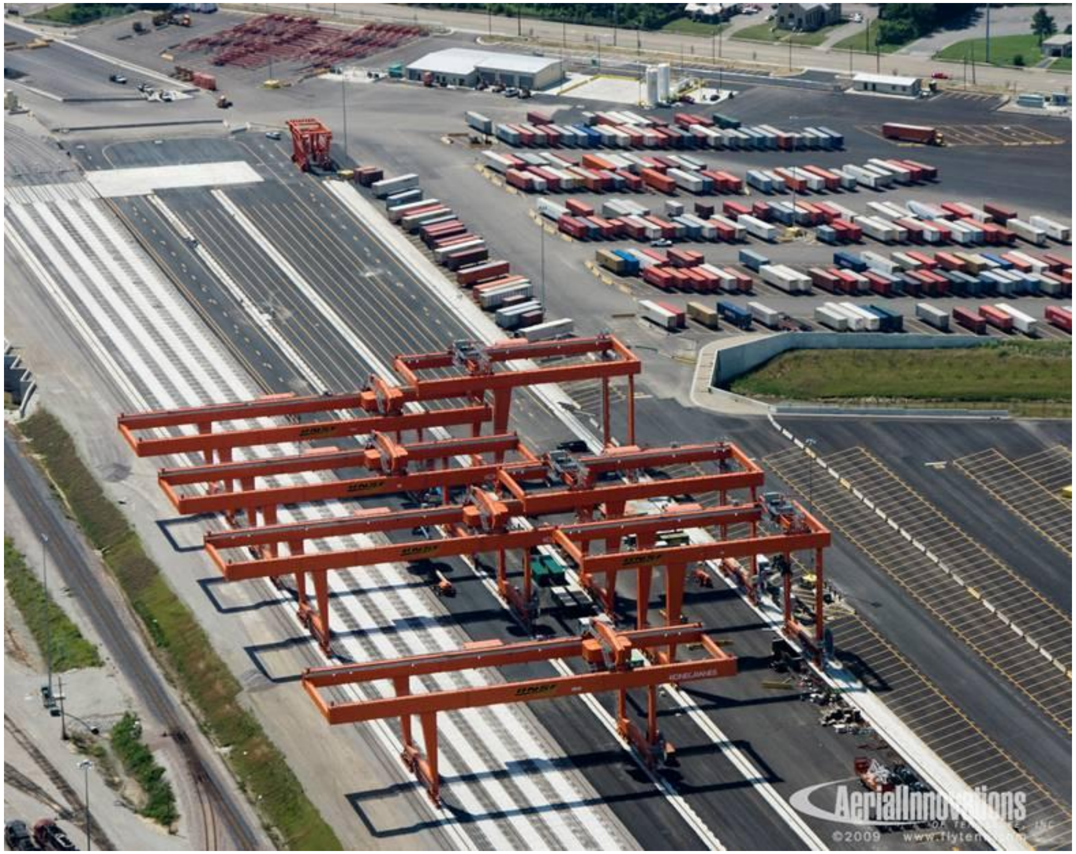
Given a set of tasks and cranes, find a sequence of tasks for each crane in order to …

Minimize crane time
Minimize truck dwell time
Maximize task priority

Subject to …

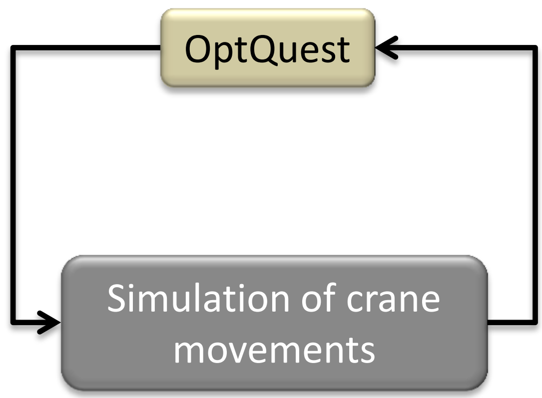
Crane availability (boundaries)
Crane speed
Precedence constraints
Task due dates
Spatial constraints

Nested Cranes



Black Box Optimization

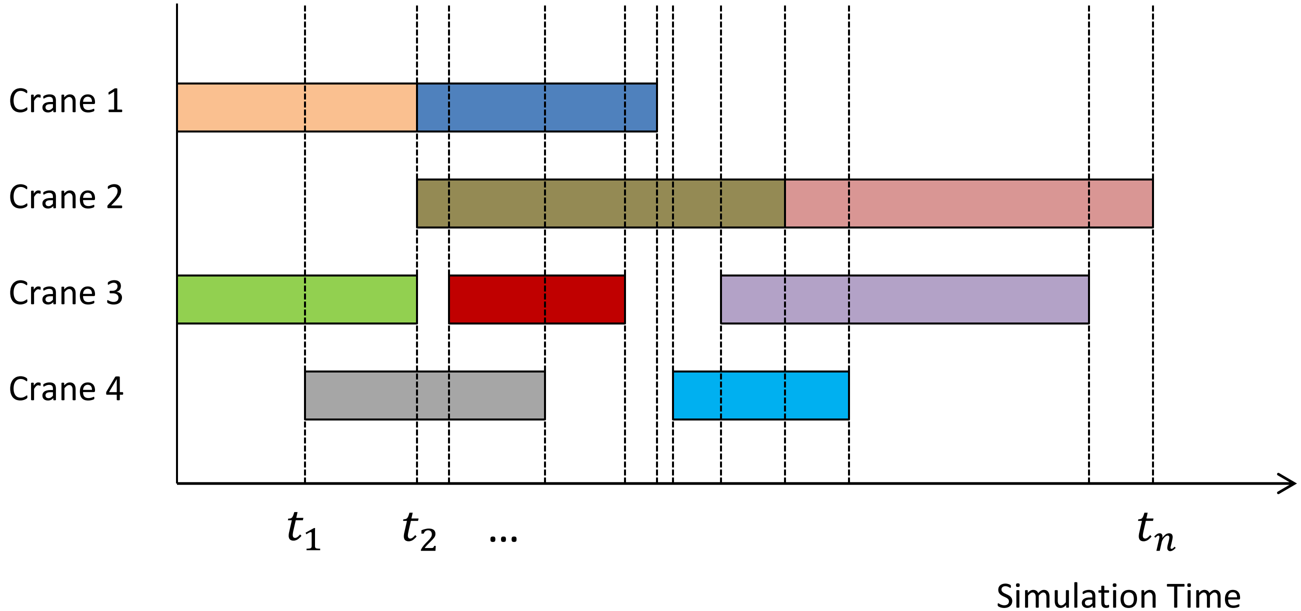
- Task assignments and sequences



- Crane time
- Dwell time
- Priority score (priority * age)
- Lateness

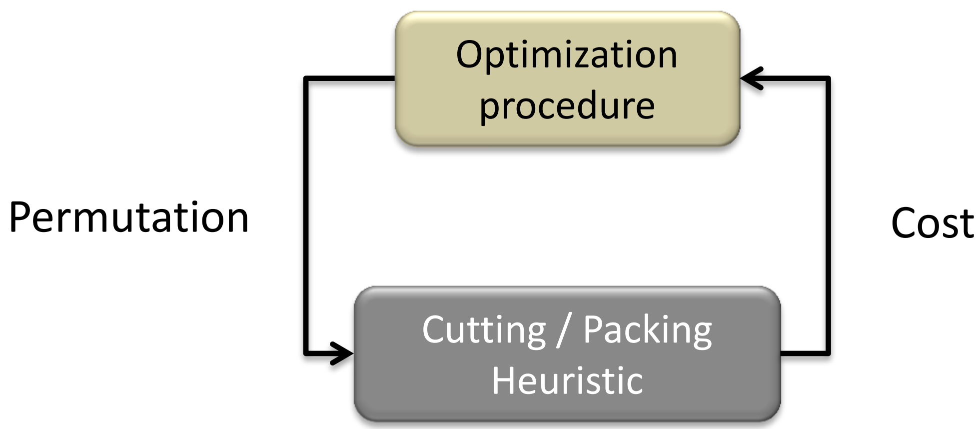
Data: - Cranes: positions & speed
- Tasks: due dates, release times, priority

Black-Box Simulation

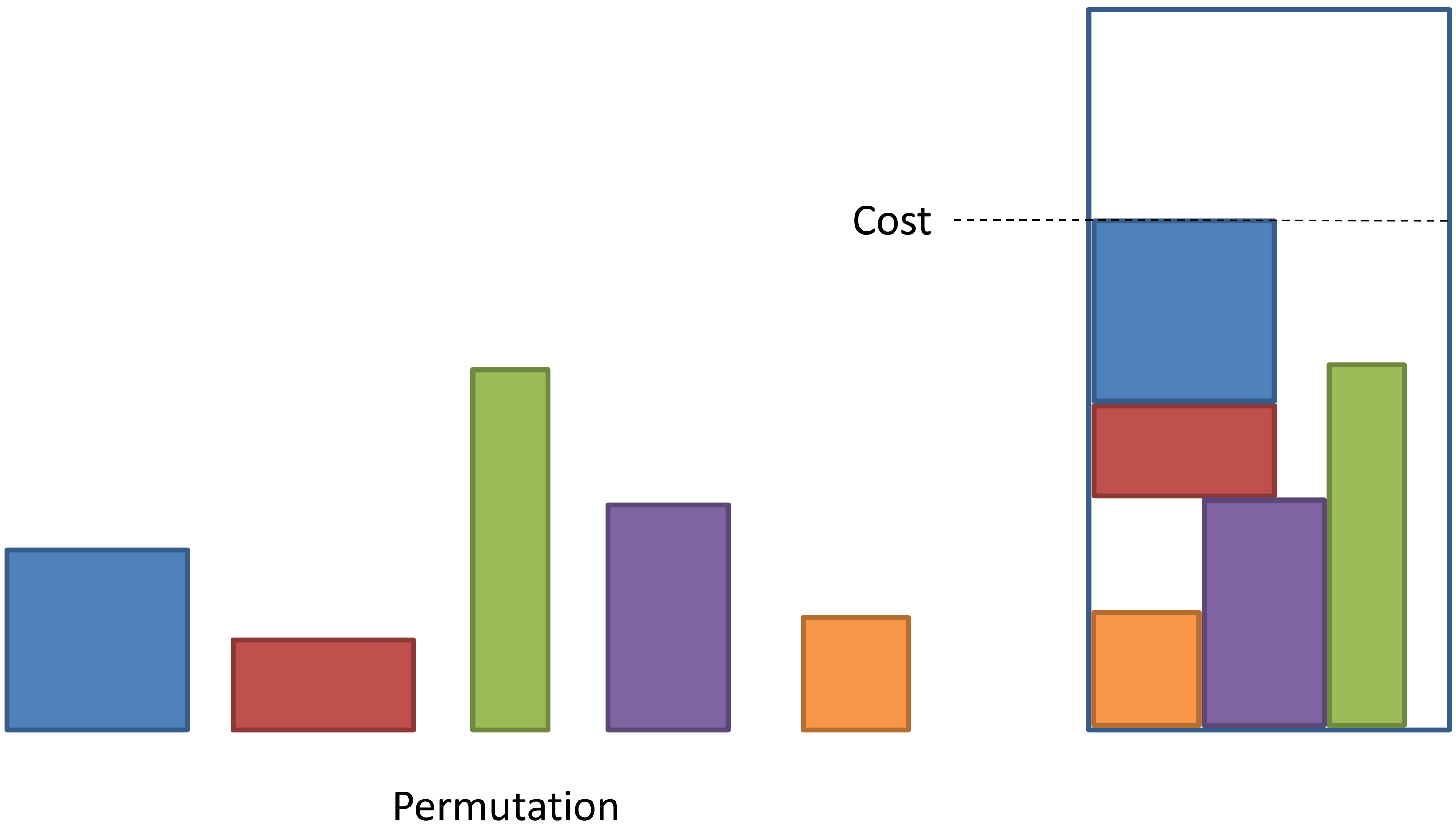


Black-box as Decoder

- Cutting and packing problems

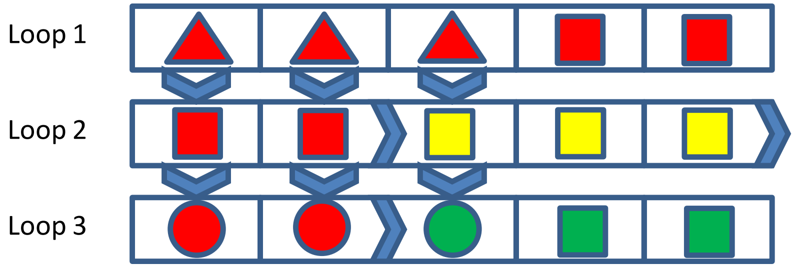


Decoder

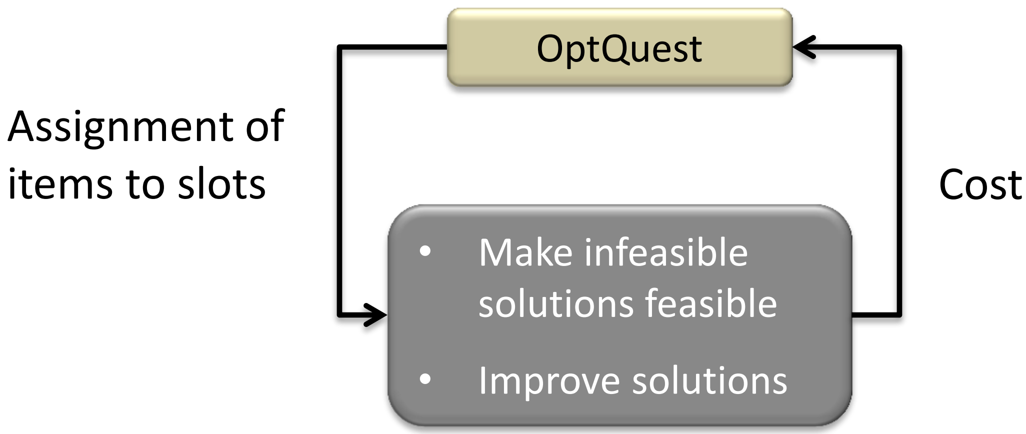


Black Box vs. Customized Approaches

- Ganguly, S. and M. Laguna (submitted) "Modeling and Solving a Cyclic and Batching Scheduling Problem with Two Types of Setups," *Production and Operations Management*



OptQuest / Short-term Memory Tabu Search



Difference between OQ/TS and Specialized VNS

Type	Demand	Colors	Geometries	Products	Difference
A	30	3	3	5	0.0%
B	40	3	3	8	1.3%
C	40	5	5	8	1.0%
D	60	5	5	15	10.6%
E	300	10	10	50	8.5%

Our Research Efforts

- Laguna, M., R. Marti, F. Gortázar, M. Gallego, A. Duarte (2012) “A Black-box Scatter Search for Optimization Problems with Integer Variables,” Working paper
- Gortazar, F., A. Duarte, M. Laguna, R. Martí (2010) “Black Box Scatter Search for General Classes of Binary Optimization Problems,” *Computers and Operations Research*, vol. 37, no. 11, pp. 1977-1986
- Laguna, M., J. Molina, F. Pérez, R. Caballero and A. Hernández-Díaz (2010) “The Challenge of Optimizing Expensive Black Boxes: A Scatter Search / Rough Set Theory Approach,” *Journal of the Operational Research Society*, vol. 61, no. 1, pp. 53-67
- Campos, V., M. Laguna and R. Martí (2005) “Context-Independent Scatter and Tabu Search for Permutation Problems,” *INFORMS Journal on Computing,* vol. 17, no. 1, pp. 111-122

SS for Integer Optimization Problems

Problem	Method	*Dev*	*#Best*
Bandwidth Coloring Problem	FCNS	2.47%	7
	SS	396.79%	0
Capacitated Task Allocation Problem	VNS	6.80%	1
	SS	8.09%	16
Maximally Diverse Grouping Problem	SO	0.16%	8
	SS	0.31%	5

Thank you!

Questions?