Optimization: from Theory to Practice

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Quintiq profile

Unique software for business operations planning and optimization

Leading software vendor
• Founded in 1997, growing at 37% CAGR since 2009
• 1000+ dedicated employees,
• Single software used by 12 000 users in over 80 countries worldwide by 290 customers
• Acquired in 2014 by Dassault Systèmes (3DS), the largest software company in France

Open collaboration with Customers and Partners
Powerful international implementation partner network.

Recognized leadership
Some Customers in France
Selected Quintiq References

- KLM
- Virgin
- Royal Flying Doctor Service
- FAA - USA
- CAAS
- airservices
- Polish Air Navigation Services Agency (PANSA)
- FAA
- LSG Sky Chefs
- Schiphol
- CPH
- Fraport
- SBB CFF FFS
- THALYS
- NTV
- Transport for London
- Eurotunnel
- DHL Express
- Schenker
- CN
- Danone
- Vion Food Group
- Salm
- OCP
- ArcelorMittal
- Constellium
- France Télévisions
- Radio France
Quintiq and Dassault Systèmes offices around the world
Best results are typically accomplished through

**Cooperation between human planner and optimization**

Planners are in control and decide when and how to use optimization.
The 3 Pillars of Quintiq Software

Business model and logic
- Each company is unique:
  - 100%-fit business model is essential
  - All business constraints and objectives must be modeled
  - Each planning level must give appropriate details

And quickly evolving:
- Quintiq models are flexible

Visualization and interaction
- Support informed decisions:
  - Ad-hoc visualization
  - Intuitive interaction with the planning
  - Real-time display of decisions consequences

Collaboration:
- Single source of data
- Real time propagation across distant users
- Scenario management

KPI based Optimization & Forecasting
- Powerful and flexible:
  - State of the art algorithms in Quintiq Optimization and Forecasting Suite
  - Easily combined and tailored to various planning needs

Fully controlled by the user:
- Propose global or partial planning on user request
- Planner defines criteria and makes the final decisions
Quintiq software overview

Integration

Optimization & Forecasting Algorithms

KPI for Informed decisions

Single source of data In-memory

Declarative model Object oriented

Business rules real-time propagation

Flexible GUI Planner in control

Flexible Business rules 100% fit

10% Customer

Industry 10% Solution

Manufacturing
Macro Planner
Company Planner
Scheduler

Workforce planner

Demand planner

Logistics planner

Standard software, Tailored solutions

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Real-time alignment of all stake-holders on the same plan.
Industry solutions / Products:
Product: Logistic Planner - as a starting point
Optimization from Theory to Practice
Our organization
Optimization design principles

• 100% coverage of all constraints and KPIs
  – Build first a good viewer, evaluator and editor of a solution
  – Check it on real data set and plans
  – Facilitate each decision with the suitable views and autonomination

• Design optimization to cooperate with the human planner
  – Allow optimizer concentrating on sub-parts
  – Allow to freeze parts of the plan
  – Allow to violate constraints using soft knowledge

• Use industry knowledge

• Combine optimization technology for best results.
### Some of our technologies

We set these world records using **the same software** our customers use to solve their planning puzzles

<table>
<thead>
<tr>
<th><strong>Quill</strong></th>
<th>Used to model construction heuristics and to combine other algorithms.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Local Search</strong></td>
<td>Efficiently making local improvements using the business logic.</td>
</tr>
<tr>
<td><strong>Mathematical Programs</strong></td>
<td>Optimizing linear goal under linear constraints; interface to CPLEX.</td>
</tr>
<tr>
<td><strong>Path Optimization Algorithm</strong></td>
<td>Population of solutions improved by Large Neighborhood Search. POA used for vehicle routing, job shop scheduling, etc.</td>
</tr>
<tr>
<td><strong>Constraint Programs</strong></td>
<td>Search while maintaining feasibility of (non-linear) constraints.</td>
</tr>
<tr>
<td><strong>Graph Programs</strong></td>
<td>Resource constrained shortest path, flow problems, minimum spanning tree, etc.</td>
</tr>
</tbody>
</table>
# Human Organization to excel in optimization projects

| Optimization Board                  | • Leads the Optimization community at Quintiq  
|                                     | • Leads optimization implementations and supports all optimization experts (BU, Products, R&D)  
|                                     | • Gathers best practices and spreads those across Quintiq  
|                                     | • Methodology, templates, examples, e-Learning courses  
| Optimization Experts in Business Units | • Configure and Extend optimizers to fit 100% of customers’ puzzles  
|                                       | • Strong industry-specific planning and optimization knowledge  
| Products Optimization                | • Creates out-of-the-box optimizers in Quintiq Products that cover a broad spectrum of puzzles found in practice  
|                                       | • Adapts and improves state-of-the-art algorithms in science and industry to fit business puzzles  
| Optimization R&D                     | • Deliver Optimization algorithms libraries  
|                                       | • Background in operations research and artificial intelligence  
|                                       | • Strong software engineering skills  

Real results
- Vlisco production increase of 16%
- Sapa WIP reduced by 20%
- LSG Skychefs vans reduced by 35%
- SIG Combibloc internal lot sizes increased by 10%

From Practice to Theory and from Theory to Practice

Quintiq R&D and Products

Optimization technology

Experience & knowledge

Performance
5% – 20% improvement for nearly every customer

Benchmarks
Logistics, Workforce, Production

> 150 World Records

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Optimization from Theory to Practice
An example: Vehicle Routing
Characteristics and constraints

Deliver packages
Delivery takes time (service time)

Trucks have maximal capacity
Going from customer to customer takes time (travel time)

Customers have time windows

Objectives (KPIs)

First minimize number of trucks (routes)

Secondly, minimize distance
A solution to Gehring & Homberger's benchmark (C1_10_7)

1000 « customers »

97 routes, 43453.92 distance
Previous WR: 97 routes, 44806.73 distance
Saved: 1352.81 distance
How we’re solving the VRPTW

Hybrid method

Variety of initial solution types

Randomized improvement heuristic

Set covering using MIP

We use single-threaded, multi-threaded or distributed optimization
Improvement heuristic: ALNS

- Sequencing using Large Neighborhood Search
- Destroy/repair heuristics
- Size of the destructions (moves) varies during the search process
• Pickup and Delivery Problem with Time Windows
  – Same hierarchical goal
  – Total load cannot exceed the capacity *at any time*
  – Adds *coupling* and *precedence* constraints.
  – Allows for *longer routes* because capacity constraint plays a much less important role

**Vehicle Routing**

**Pickup and Delivery**

*routes*
2 routes because of capacity restrictions

*pairs*

*route*
1 route because picking up *and* delivering
World Record overview

VRPTW World Records by Puzzle Type

VRPTW World Records by Puzzle Size

PDPTW World Records by Puzzle Type

PDPTW World Records by Puzzle Size

Status as of 31 Dec 2015
Translating Theory to Practice

Additional requirements

Larger instances

Dynamic problem
Recursive solution

Plan ±38,000 trips
On ±4,200 drivers
The Practical Case

Plan ±38,000 trips

On ±4,200 drivers

Customers have time windows

First, minimize the number of trucks

Optimize Balanced Set of KPIs

Covers the whole US in one go
Additional requirements for this customer

- **Roaming Drivers:**
  - Drivers are on the road for a week before going home.
  - While planning today, orders for tomorrow are unknown.
  - The chance for the driver to go back home with a load need to be estimated

- **Night Rests:**
  - Driving regulations (hours a driver must rest as they have exceeded their driving or working time).

- **Dynamic Problem:**
  - The parameters of the problem constantly change based on real-time feedback, updates on orders, driver routes, etc.
Other requirements from other customers

- **Outsourcing/subcontracting:**
  - other trucking company takes care of the transport in their own trailer

- **Time-varying demand:**
  - Some customers replenish inventory (Oil&Gas), where if we deliver later we must deliver more.

- **Multi-modality:**
  - trailer can move from truck, to train or barge and then back to truck again.

- **Trailer swapping:**
  - truck and trailer are de-coupled at a certain location and trailers are interchanged. This can save total driving distance by as much as a factor 2.

- **Cross-docking:**
  - unloading orders from trailers at a cross dock location and recombining orders in other trailers.

- **Contamination groups:**
  - Certain goods cannot be placed next to each other in a trailer or even within the same trailer, e.g. washing powder (emitter) and lettuce (receiver)

- **Vehicle-to-site compatibilities:**
  - A site might not be suitable for all vehicle types due to required way of unloading, height restrictions, etc.
Size and Dynamics

- Due to problem size, master problem is cut into sub-problems which are solved in a distributed way.
- High level algorithm: Large Neighborhood Search
  - Scatter
    - For each compute node, the Controller selects a cluster of routes and kicks off optimization.
  - Gather
    - Results are collected at the Controller.
    - Set cover algorithm picks the best combination of drivers planning.

38,000 trips
4,200 trucks
Distributed Optimization

Controller

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Quintiq sets new world records for FJSSP

Quintiq holds 119 world records for flexible job shop scheduling

The Flexible Job Shop Scheduling Problem (FJSSP) is an extension of the classic Job Shop Scheduling Problem, which has been studied since the 1960s.

<table>
<thead>
<tr>
<th>Instance</th>
<th>Former World Record</th>
<th>Date</th>
<th>Quintiq's World Record</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dauzere 14a</td>
<td>2162</td>
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<td>May 2014</td>
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<td>Dauzere 03a</td>
<td>2229</td>
<td>Oct 2008</td>
<td>2228</td>
<td>Mar 2013</td>
</tr>
</tbody>
</table>

Note this is not limited to vehicle routing...

We recently found new world records (using Conflict Directed Clause Learning in CP)
Case study: Vlisco

**Background**

- Textile manufacturer Vlisco designs, produces and distributes colorful fashion fabrics.
- Quintiq implemented an application to assist with order acceptance (determining delivery dates) and sequencing.
- KPIs are delivery performance, adherence to plan, and setup minimization.

**Why was it challenging to optimize Vlisco’s operations?**

- Long routes (up to 25 treatment steps)
- Circular routes (visiting the same resource multiple times)
- Minimal and maximal delay between activities
- Rework
- Setup times
- Order combining (certain pairs of orders can be processed in parallel)
- Diverging material flow (order may be split somewhere in the middle and the different parts then get processed differently)
- Up to 10,000 activities (400 orders * 25 treatments steps)
Optimization from Theory to Practice: Recent progress
We see in practice that tuning optimizers is non-trivial and time consuming. We’ve created a library that can tune any Quintiq-developed optimizer with minimal effort.

This library helps us:

- Get good settings more quickly
- Get better settings

Optimization (in the model)
Automatic Parameter Tuning: Success stories

A set of 23 “Vehicle Routing Problem with Time Windows” instances:
- 41% faster for a good solution
- 95% faster for a great solution

A practical scheduling puzzle:
- 87% faster (82s to 11s) to improve by 10% best known solution
- 94% faster (307s to 17s) to improve by 5% the best known solution
- Surprising insights on parameters effects
Problem data is uncertain, unreliable or unknown

- Travel time
- Service times
- Processing times
- Machine availability
- Human resource are not predictable/deterministic
- Multiple sources
- Input errors

R&D in Optimization under Uncertainty:
several MSc and PhD projects partly funded

Predictive analytics is a key component of our solutions
Conclusion
Why Quintiq is good at optimization in practice

**Optimization strengths**

- 100% fit
- Optimization designed to cooperate with human planner
- Broad set of optimization technologies
- Expertise to map customer puzzles to optimization technologies

- Productized knowledge on how to do optimization in projects
- World-class results from academic puzzles to real-life customer puzzles
Why OR specialists join Quintiq

• Wide panel of roles in Quintiq that require an OR background

• Always challenging work while having a lot of fun

• We bring value to our customers
  – By translating problems from practice to theory and then technology from theory to practice.