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Industrial Optimization Seminar
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Applying Optimization in the Airline Industry

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Carmen Systems

Outline

- Who is Carmen?
- What type of optimization problems arise in airline operations?
- What are necessary conditions for a successful optimization application?
- What keeps an optimization company competitive?
- What has Carmen done over the years?
- Which future trends do I see?

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Carmen Systems

Profile

- Carmen is an industrial software and service supplier within areas where optimization matters
- Carmen develops, markets and implements *resource optimization* solutions
  - for clients primarily in the *transportation* industry
  - current focus is *airlines* and *railways*
  - further potential within *logistics* vehicle routing, ports, airports, container/cargo, sports scheduling and mining
- Strong client base including five of the world's ten largest airlines and the two largest railways in Europe

Growth

- Founded 1994 (with roots in Volvo – 1986)
- Profitable with 290 employees in Sweden, Austin TX, Brisbane, London, Mexico, Montreal and Singapore

Impact

- Carmen offers *proven* bottom line *cost savings* in the magnitude of 3-15% for two of the three largest cost drivers: crew & fleet
- Core business model based on rental agreements - cost savings are immediate for clients

Client Base – Airlines …

AeroMexico
Lufthansa
Air France
Mexicana
Alitalia
nwa
Northwest Airlines
Condor
British Airways
Philippine Airlines
Delta
Singapore Airlines
widerøe
Britannia
Finnair
Saudi Arabian Airlines
Iberia
easyJet
Spanair
SAS
song
KLM Royal Dutch Airlines
virgin atlantic

- This represents
  - > 150,000 pilots and flight attendants worldwide
  - ~ 25% of market share
- Additionally

Continental Airlines

UNITED

Railways, and others...

SNCF
SJ
AMTRAK
Die Bahn DB
green cargo
Metra The way to really fly.
RailCorp
Keolis
DSB
VLine
BART
FirstGroup
SL
Citypendeln
pacificnational
FREIGHT AUSTRALIA
railgourmet
connex

AUSTRALIA POST Delivering more than ever
TNT
NHL
Royal Mail
CLIENTLOGIC
ATOC
New Zealand Post
thetrainline the easy way to buy train tick
Queensland Government
Cadbury Schweppes
greater WELLINGTON REGIONAL COUNCI
incitec
TOLL
Transperth
Capgemini CONSULTING.TECHNOLOGY.OUTSOURCING
MapInfo Business Partner
First transforming travel
energex
Auckland Regional Council TE RAUHITANGA TAIAO
VENTURA
TRANSPORT NSW

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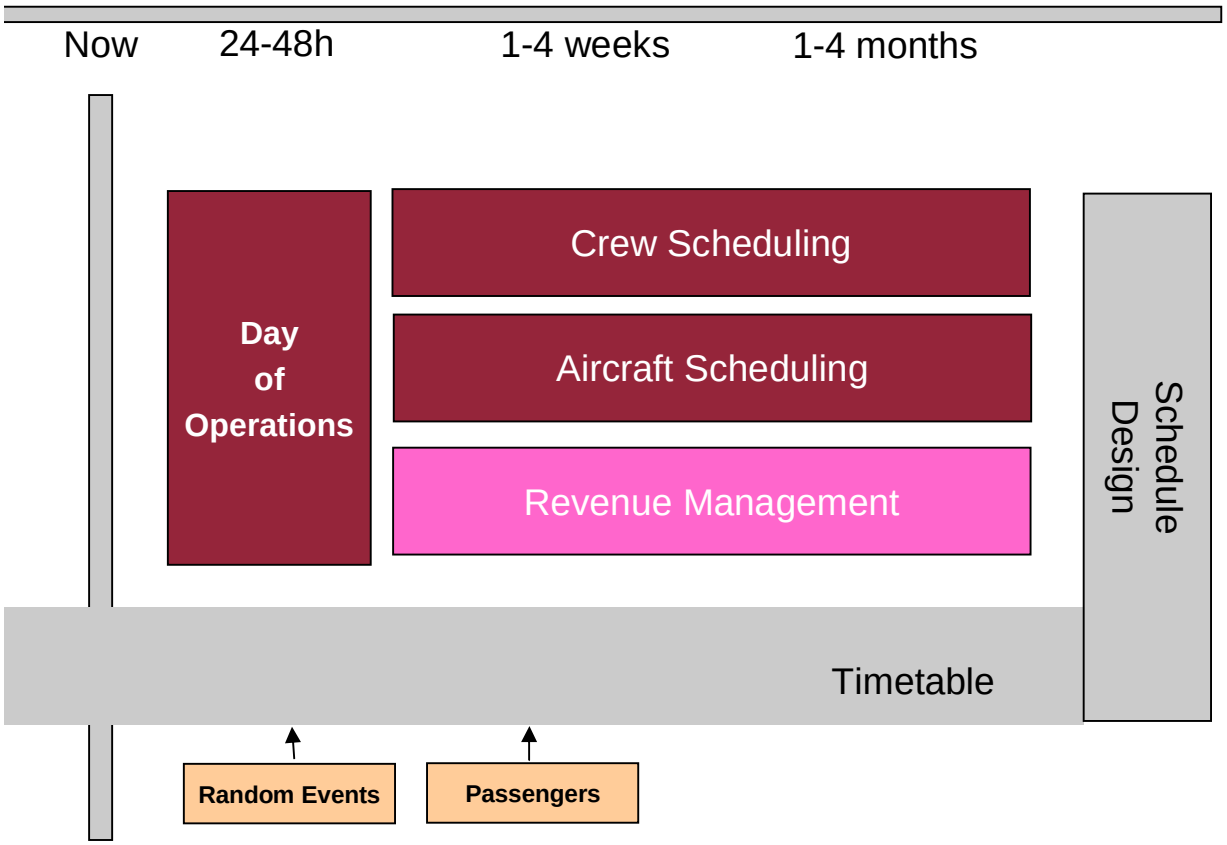
Airline Planning and Scheduling

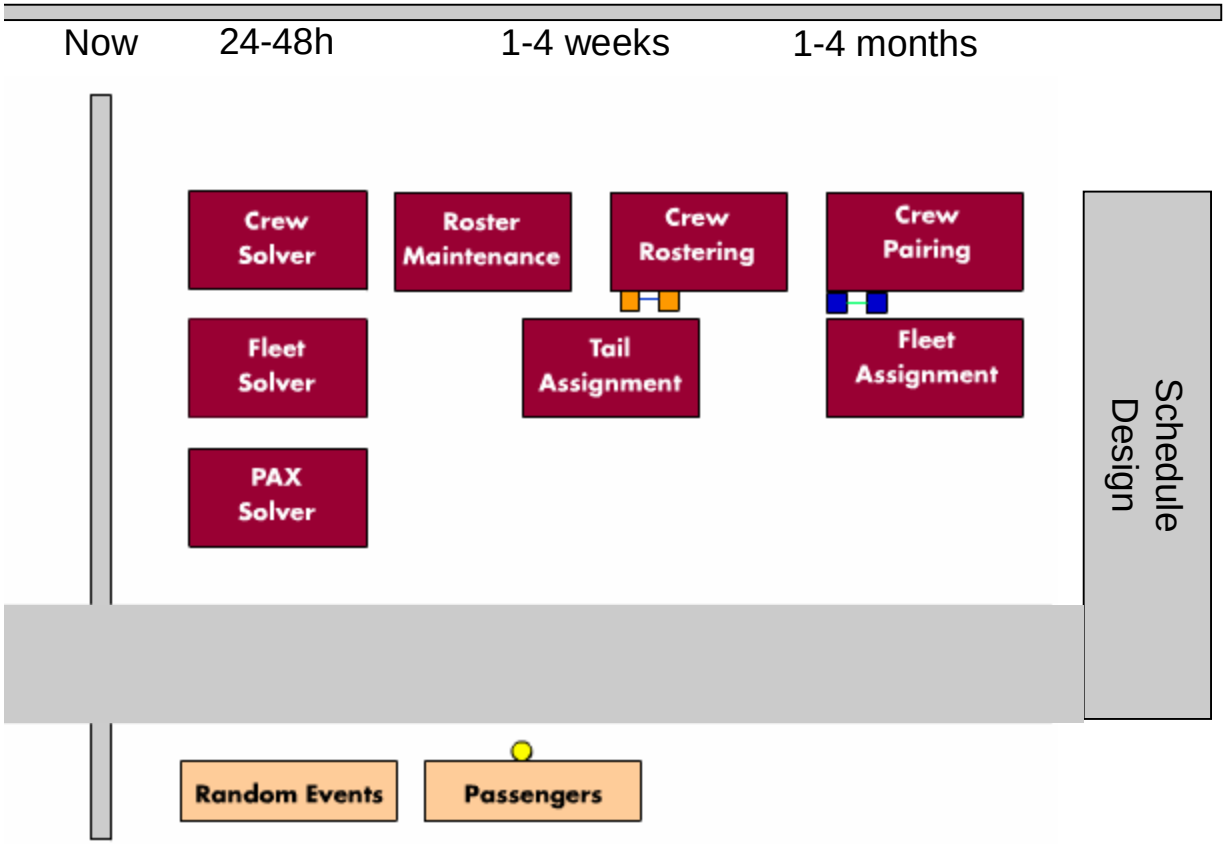


(not to scale)

Example: **American Airlines**

- 840 a/c
- 2,400 daily flights to 149 cities
- 13,300 pilots in 11 bases
- 25,000 F/A in 19 bases

Airline Operations



(not to scale)

Characteristics in general

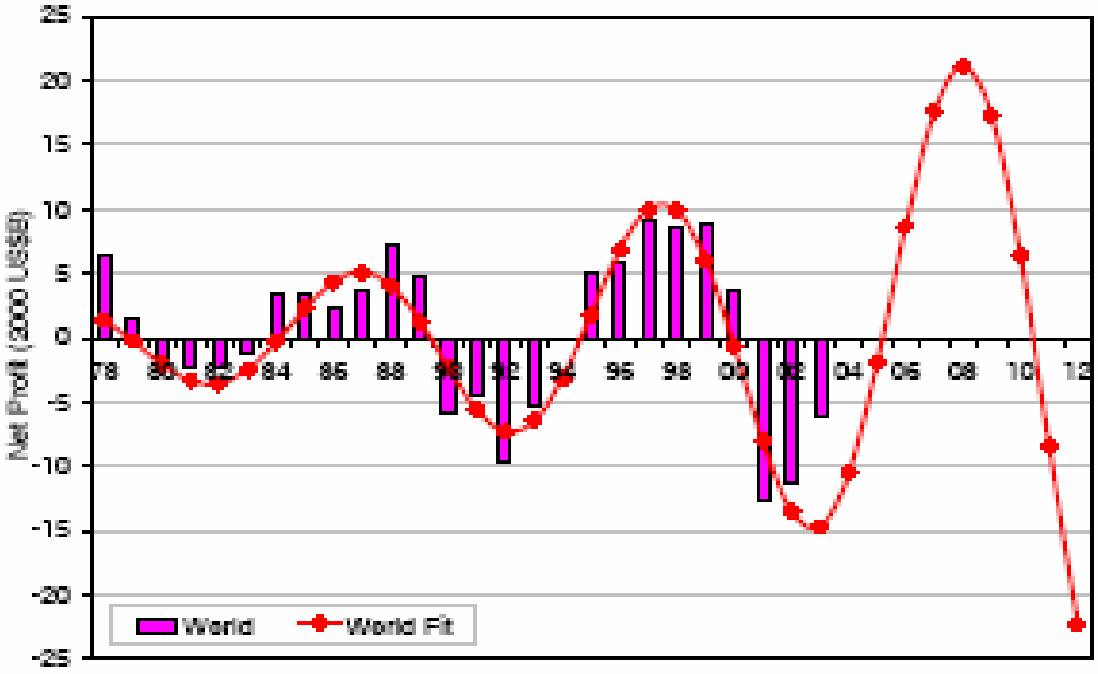
- § Size
- § Complexity
- § Continuous change
- § Decomposition vs. integration
- § Planning vs. operations
- § Impact on costs and profits

è Nontrivial Optimization Problems

Profitability of Airline Industry

Net Profit Analysis of World Airlines with Extrapolation

Source: Jiang and Hansman, 2004



Selected References

- H.H. Jiang and R.J. Hansman. An analysis of profit cycles in the airline industry. International Center for Air Transportation Report ICAT-2004-07, MIT, December 2004.
- R. Tam and R.J. Hansman. An analysis of the dynamics of the US commercial air traffic transportation system. International Center for Air Transportation Report ICAT-2003-06, MIT, November 2003.

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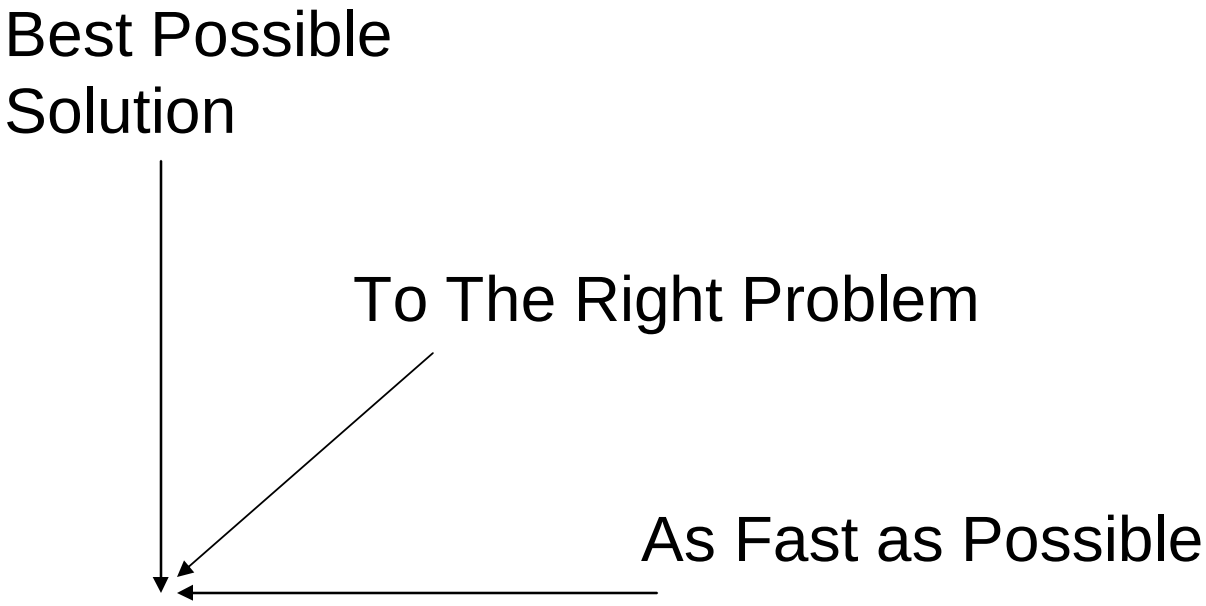
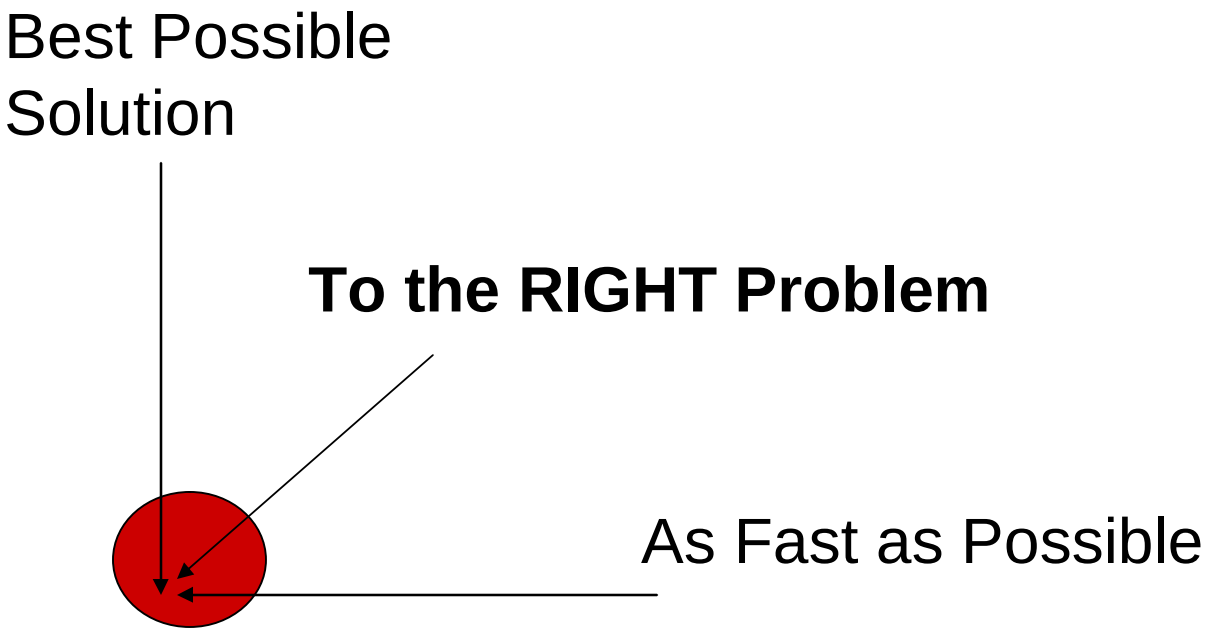
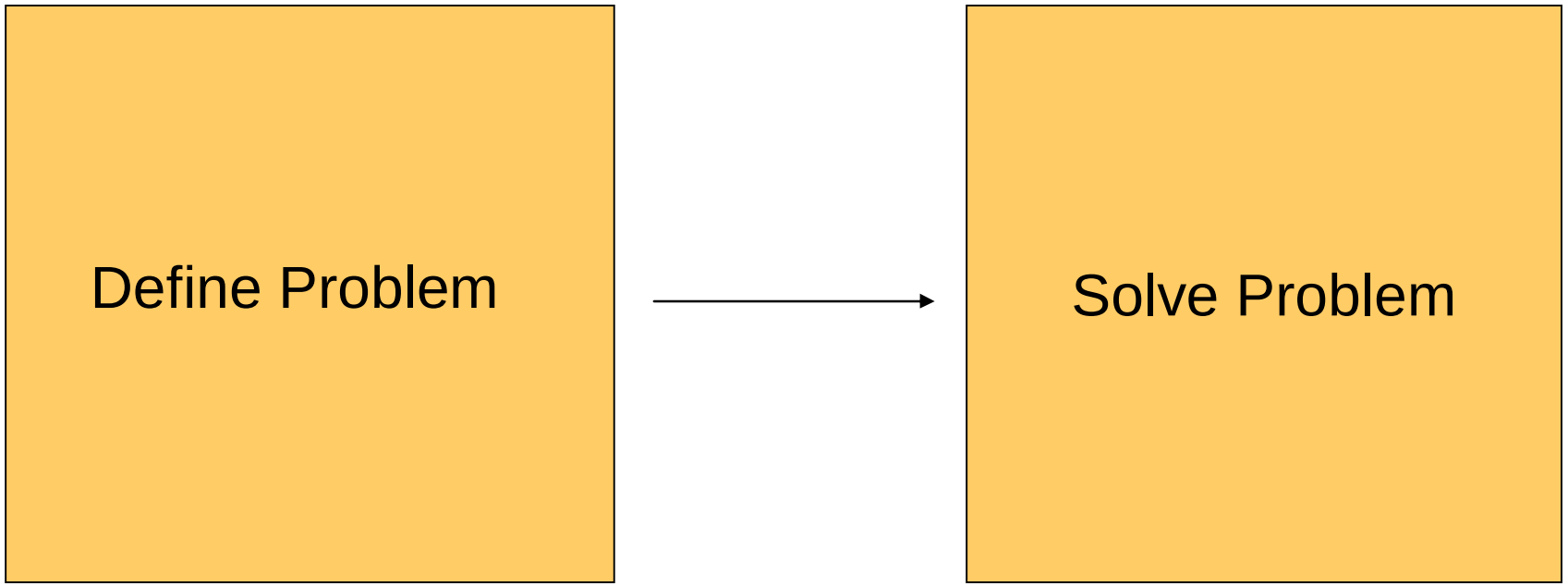
Optimization is about…



Problem solving is about…

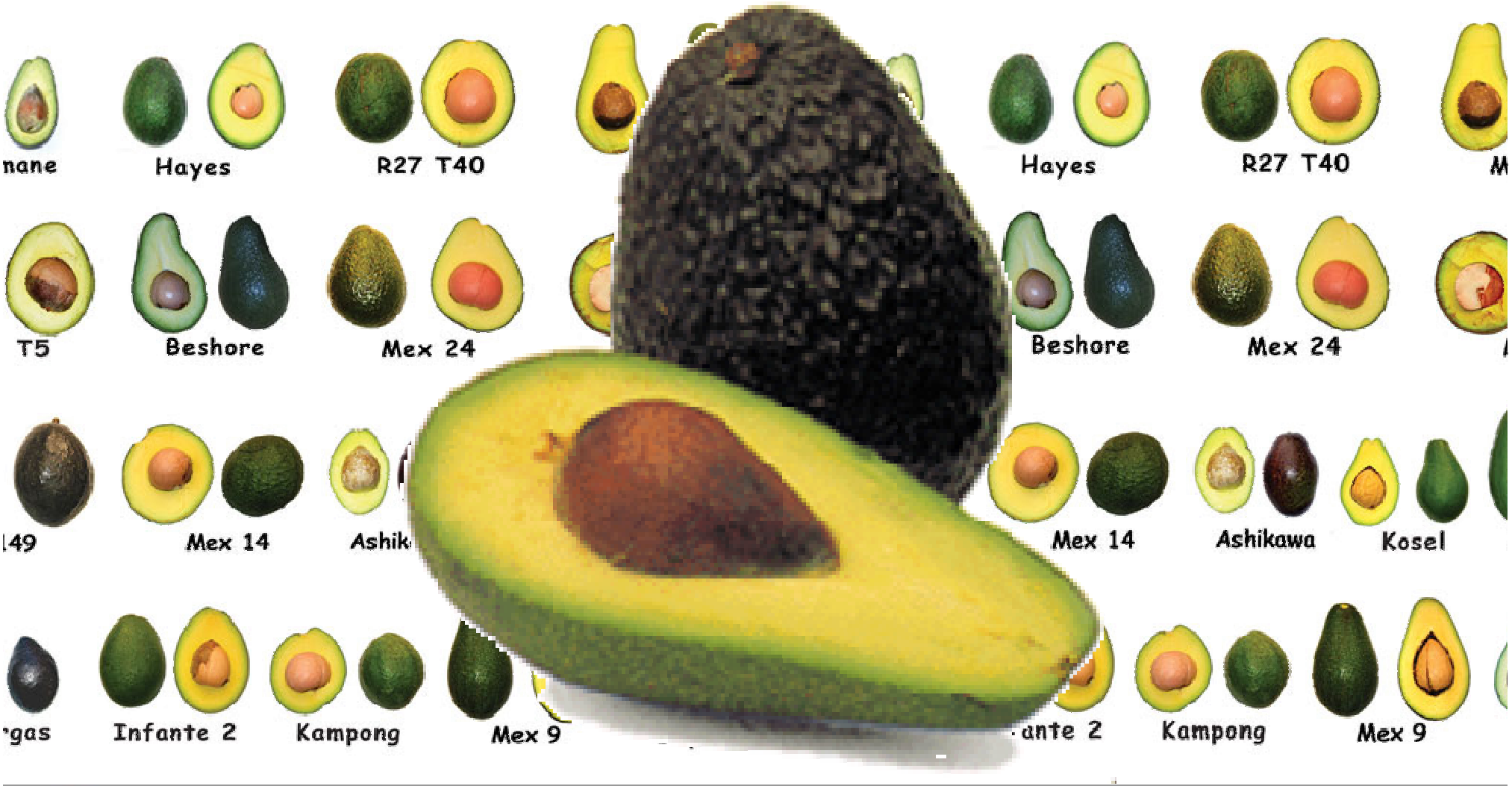


Problem Solving Paradigm

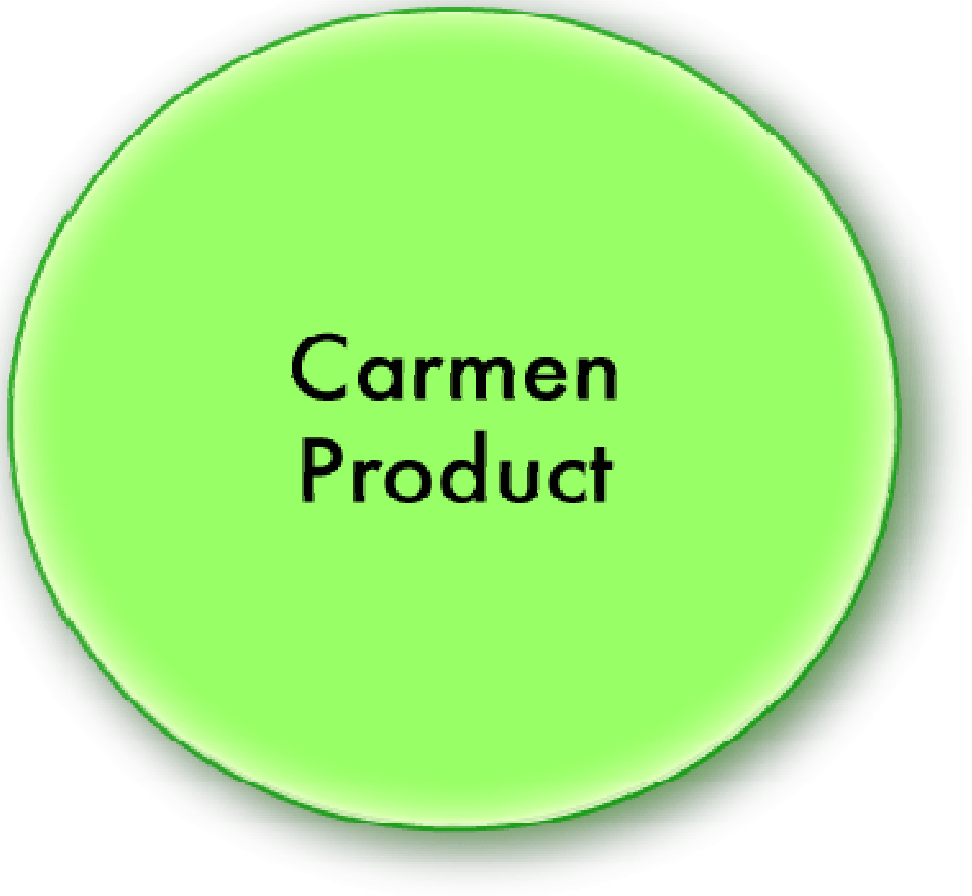


Separate problem definition from problem solution and support a focus on the modeling aspects.

Problem Solving and Avocados

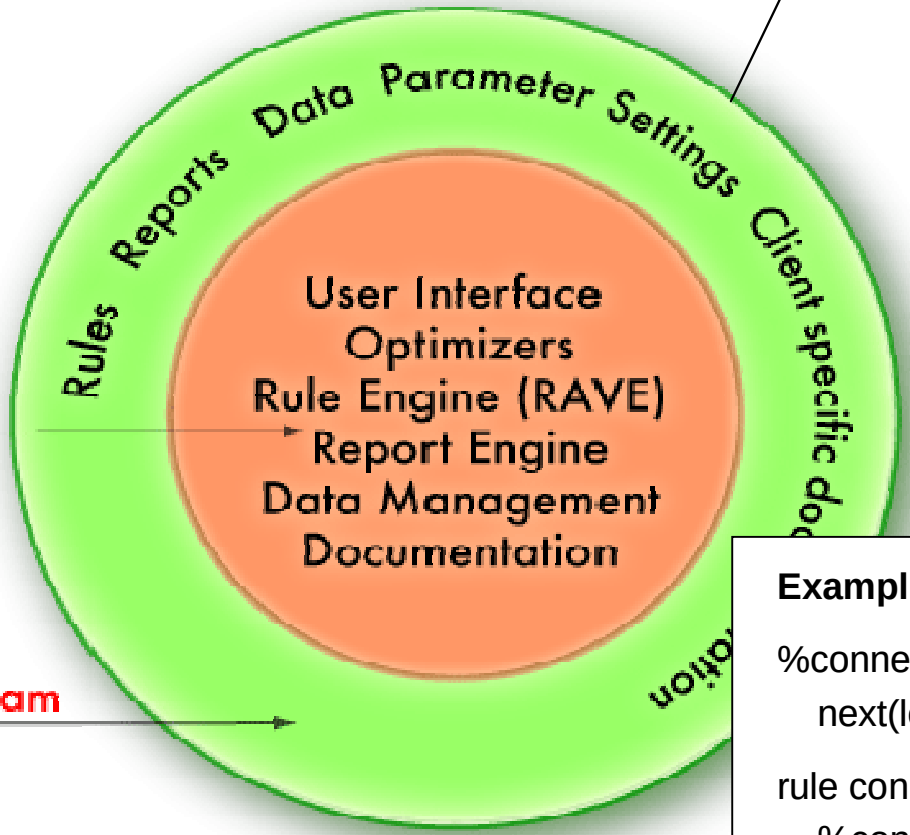


The Carmen Avocado



The Carmen Avocado

- Legality
- Quality
- Costs
- Reports
- Interfaces
- Colours
- etc...



Carmen R&D

"CARMSYS"

Air or Rail: Carmen team

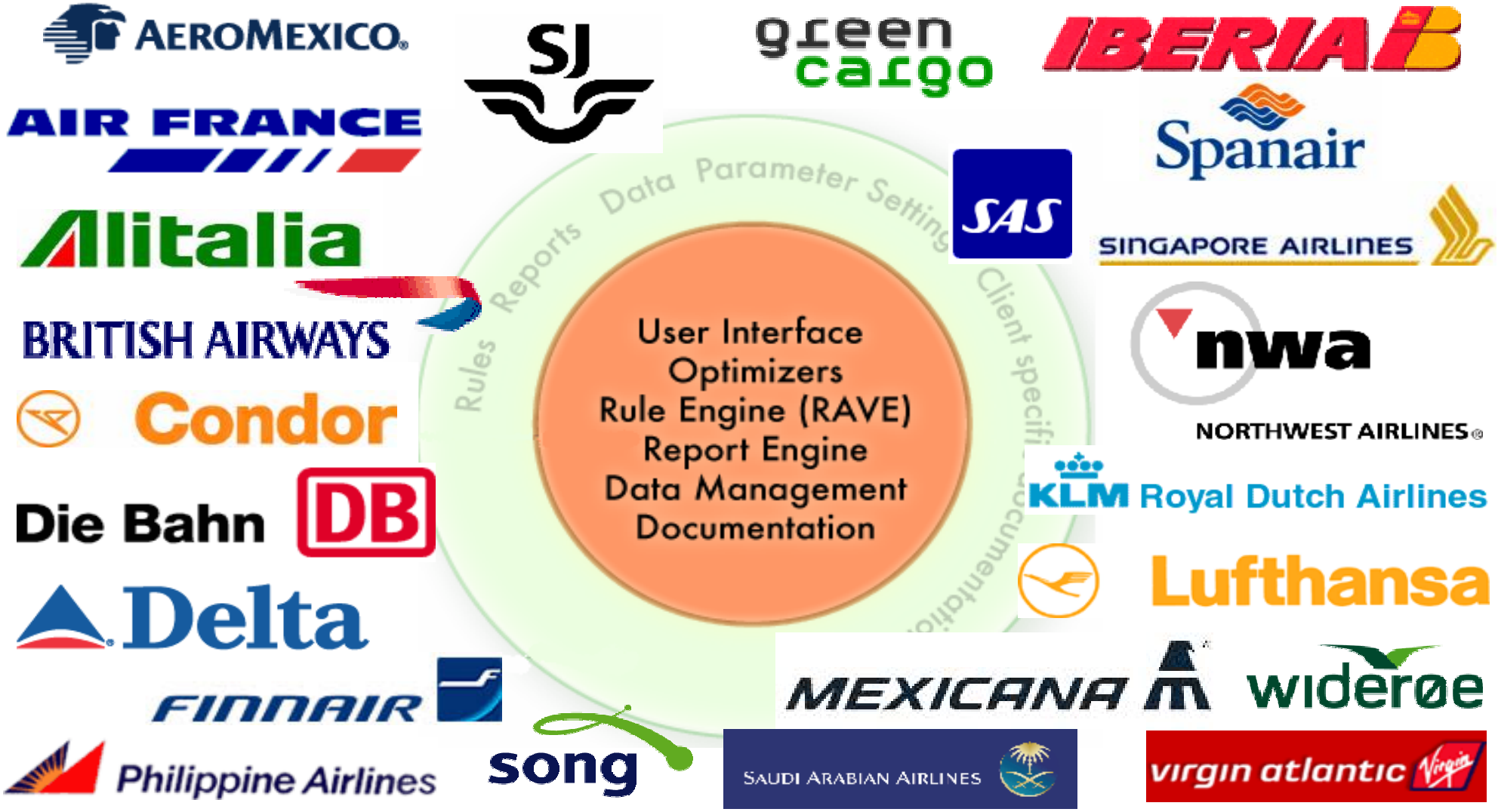
"CARMUSR"

Example:

```
%connection_time% =
    next(leg(duty), departure) - arrival;

rule connection_time_ok =
    %connection_time% > 0:30;
end
```

The Carmen Avocado



Success Factors for Applied Optimization (1)

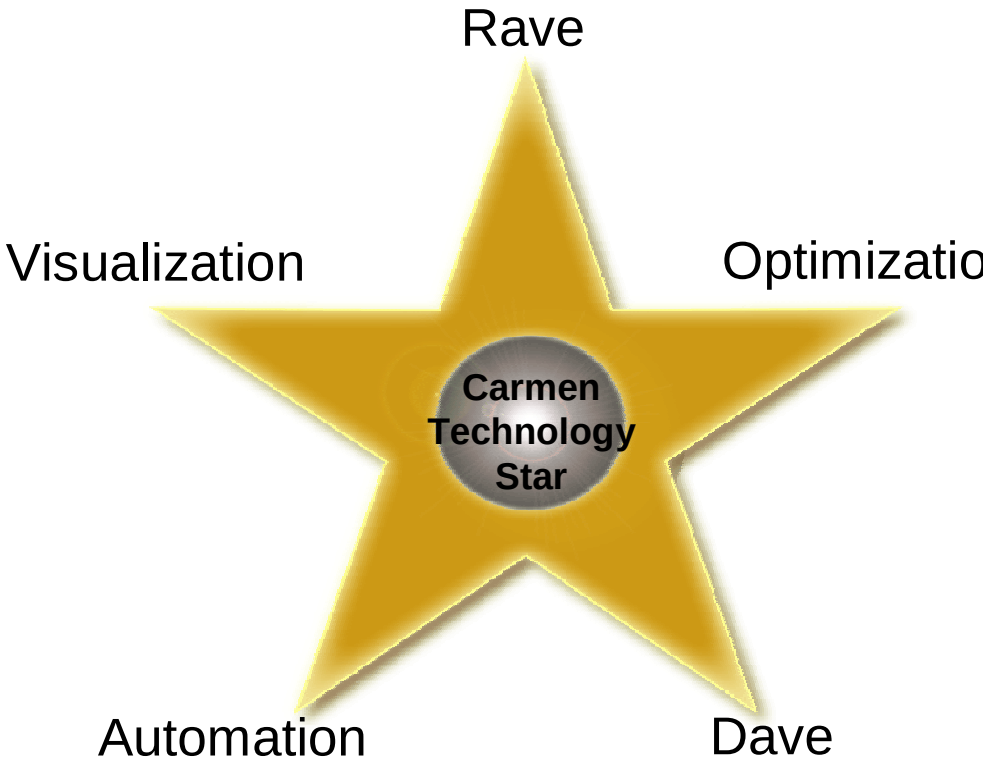
Optimization needs to contribute to

- Problem Solving Paradigm
  - How can we adapt to changes?
- Improvement
  - How can we find better solutions?
- Understanding
  - Why do our planned and operated schedules differ?
- Simplification
  - How can we make processes more efficient?

Success Factors for Applied Optimization (2)

To this end, optimization requires a star!

- Modeling capabilities
- State-of-the art algorithms
- Intuitive interfaces
- Workflow automation
- Data management



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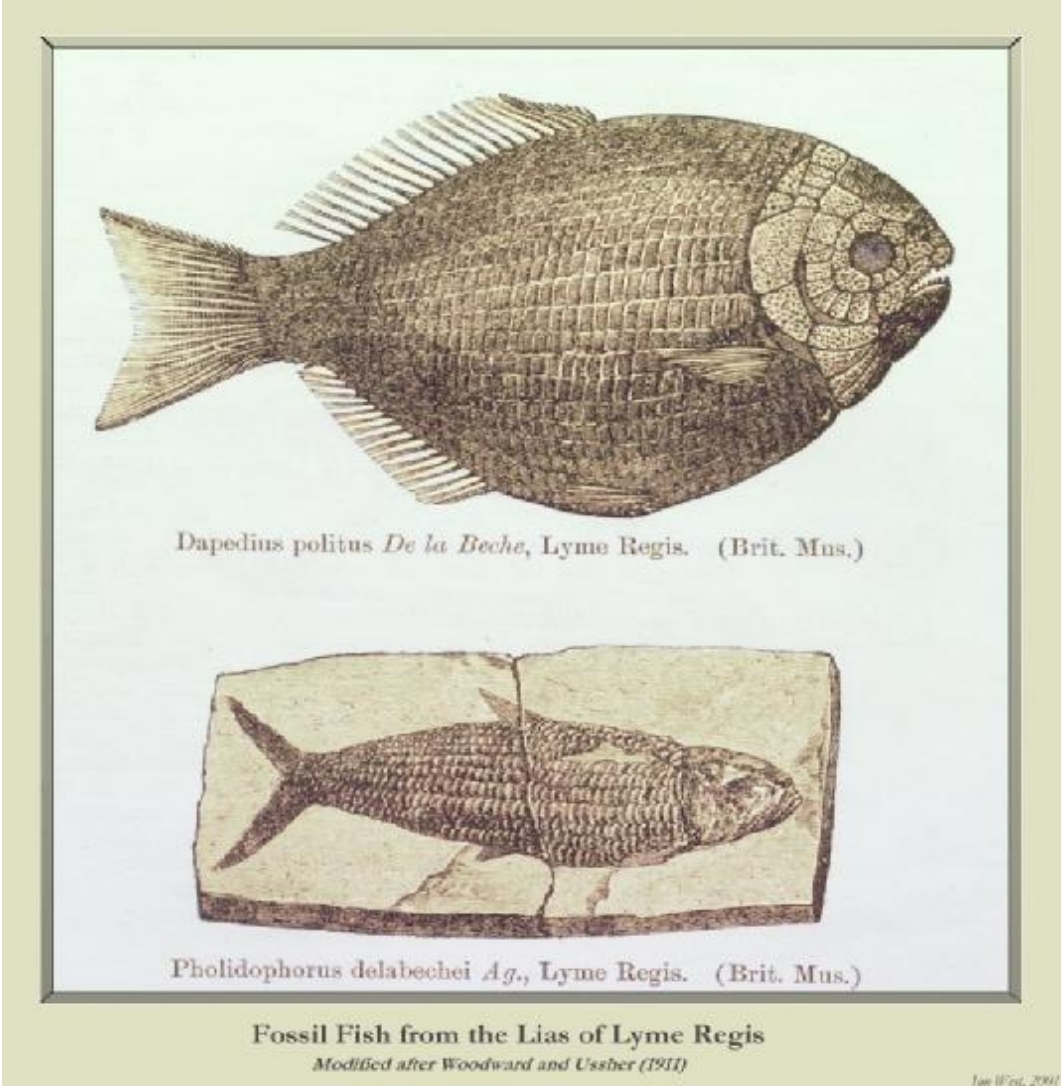
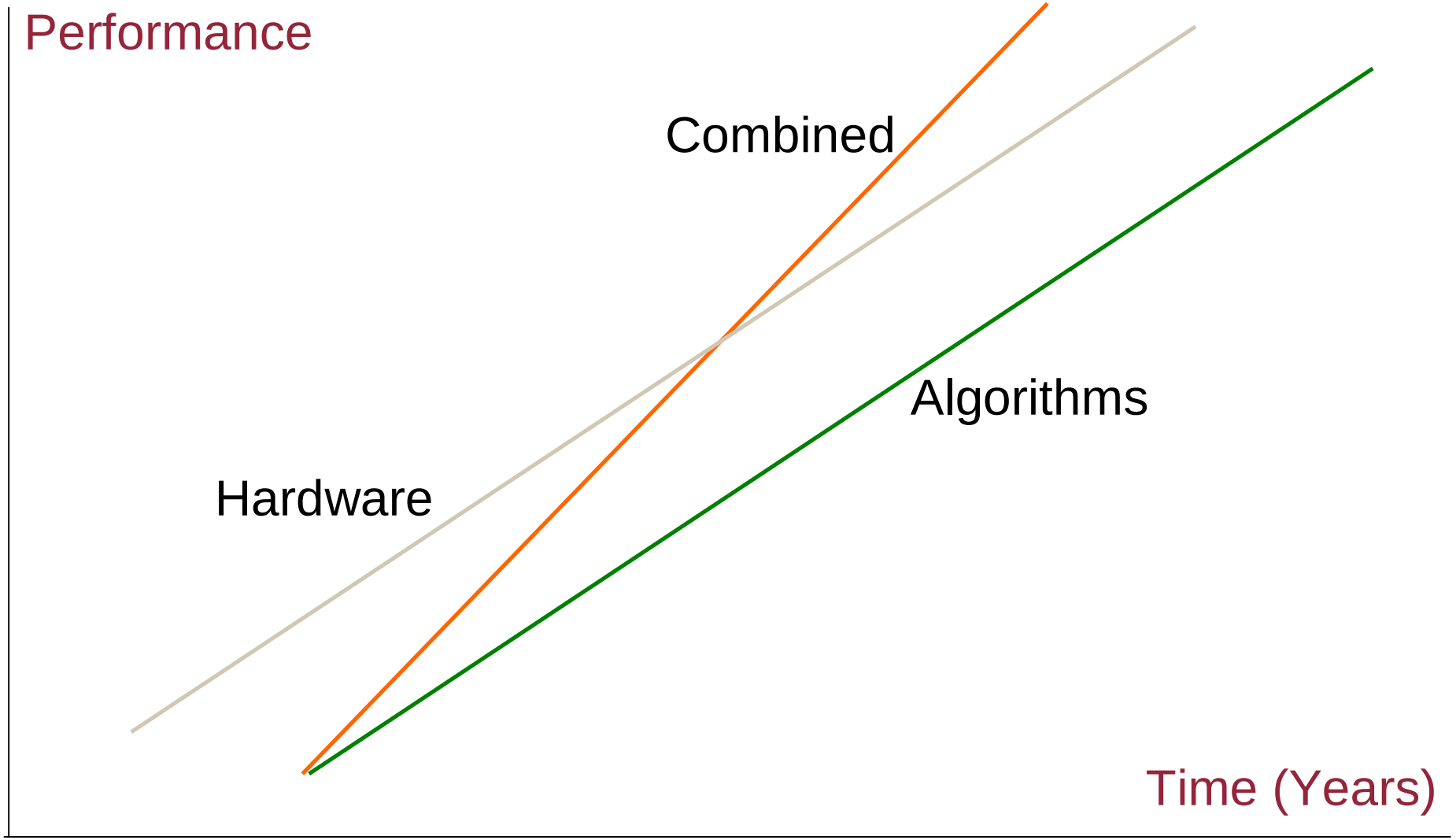
The Fate of a Technology Company?



Fossil Fish from the Lias of Lyme Regis

Modified after Woodward and Ussher (1911)

Environment

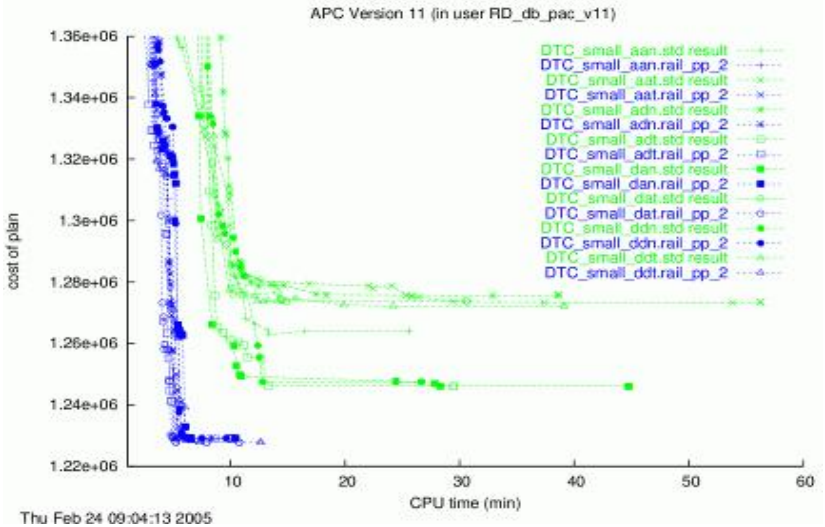


Follow the law. Carmen’s law states that optimization performance must improve with every release.

Carmen's Law in Practice

- New versions of core software is delivered every year, included in long term rental agreements
  - § immediate and measurable improvements in new version for all rental clients
- § Carmen's solutions is showing continuous large improvements
  - § also in mature segments and with mature products
- Increases the ability to solve more complex problems

Performance of Carmen v12 (released in September 2005) vs Carmen v11



higher speed,
lower cost
higher predictability

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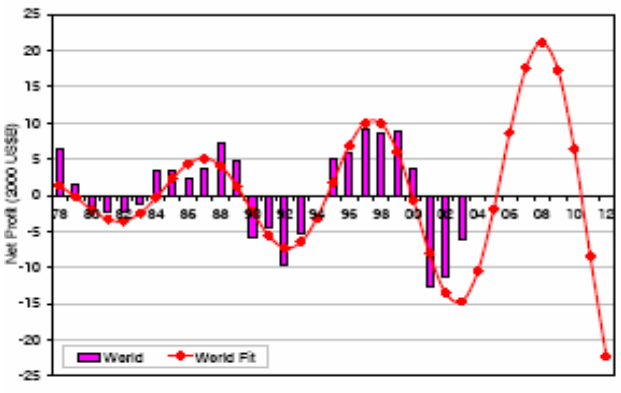
History of Carmen



1988: Carmen signs first contract

1998: 75% of EU crew scheduled by Carmen

2002: Product for Planning and Operations

2003: Northwest and Delta sign

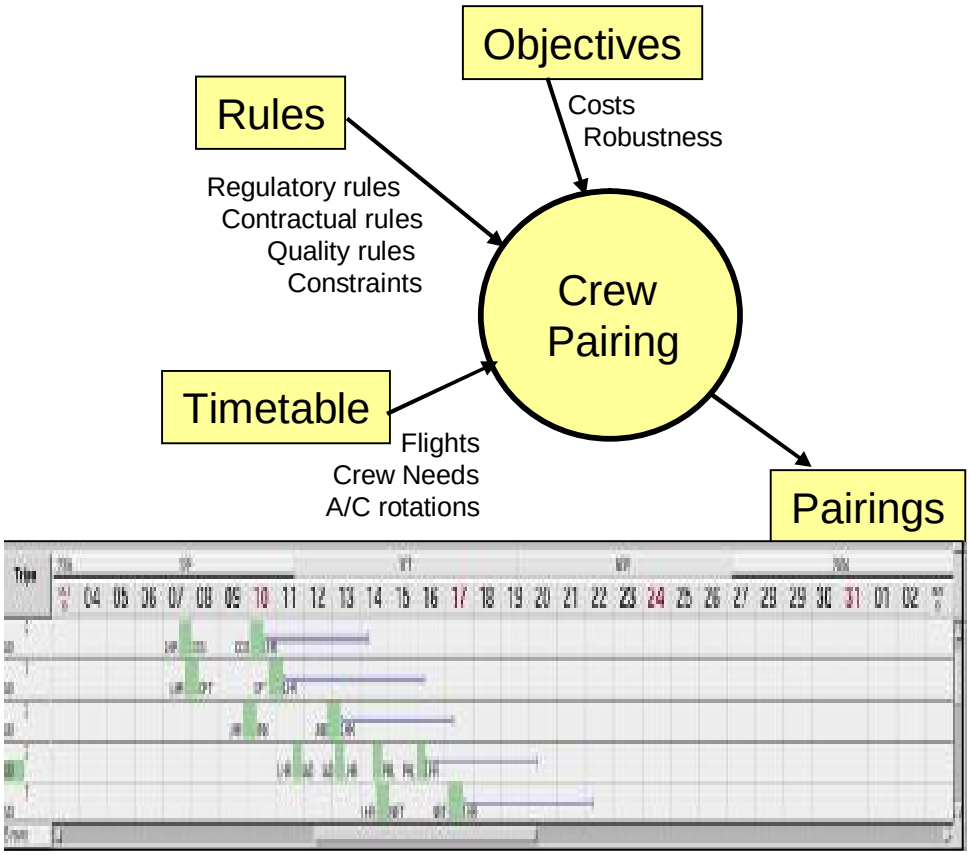
2005: ~25% of crew worldwide scheduled by Carmen

1991

2001

2011

Crew Pairing Optimization



Set Partitioning Model:

$$\min c^T x$$
$$\text{s.t. } Ax = b$$

min	c_1	c_2	c_3	c_4	c_5		
leg 1	1	1	0	1	0	=	1
leg 2	1	1	0	0	0	=	1
leg 3	0	0	1	0	1	=	1
leg 4	0	1	1	1	0	=	1
leg 5	1	0	1	1	1	=	1

è "Generate-and-optimize" with Rave

Problem Sizes:

- Air: up to 1,000 legs per day (Rail: ~6,800)
- Up to 500,000 columns and several thousand rows

History of Carmen Pairing

1990: LH project starts; ”split improve” + other ”tricks”

1990-1997: Ongoing benchmark ”battles”

1998: 75% of EU crew scheduled by Carmen

2003: Northwest and Delta sign

2002: CG outperforms other methods in general

2005: ~25% of crew worldwide planned with Carmen Pairing

1988/89/90: 1st GUI; ’general generation”; Rave + prob1 [AT&T: Korbex at DL]

1994+1996: Experiments with column generation

1997: CG work starts; ”daily” with CPLEX

1999: 1st CG release; ”weekly + dated” with paqs

2000: CG solves US problems; performs better than other methods in most cases

Future: Expand scope and integrate with other resource areas

1991

2001

2011

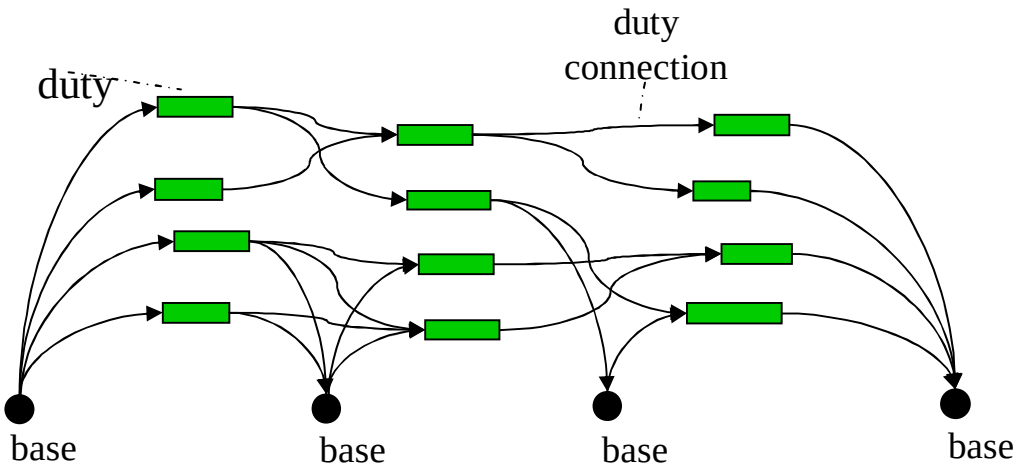
Lessons Learned

- First heuristic solutions resembled what users expected and were better than manual solutions
- Great starting point with most difficult pairing problem in Europe
- State-of-the-art was challenged from the beginning and ensuing benchmarks increased market interest
- Competition provides experience and makes you better
- When solutions were close, Rave and first reference made the difference
- Early optimization engine was a “tool-box” and supported experimental development

What's Inside?

Competitive Advantage

- Column generation
  - Dynamically refined duty networks
  - Connection fixing
  - Deadhead selection
  - Many small tricks
- IP Solver
  - PAQS (earlier prob1)
- Modeling capabilities
  - Rave
- System architecture
  - Avocado



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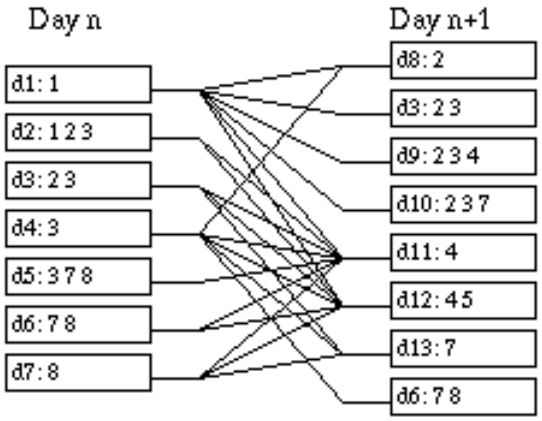
- D. Wedelin. An algorithm for large scale 0-1 integer programming with application in airline crew scheduling. *Annals of Operations Research*, 57:283-301, 1995.

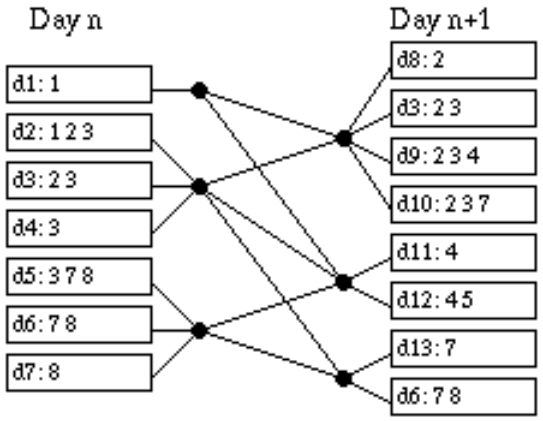
(See also http://www.carmensystems.com/research_development/research_reports.htm)

The Dynamically Refined Duty Network

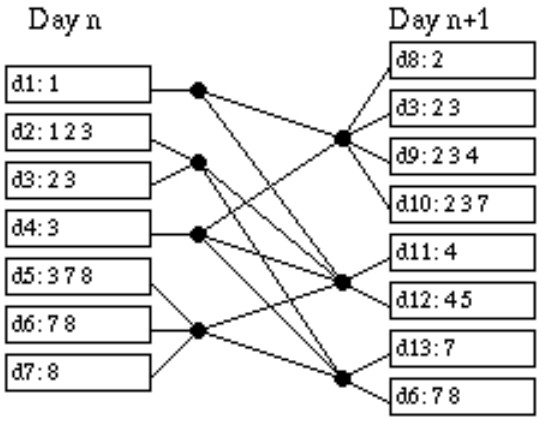
- Connects duties and forms chains of legs
- Contains basic legality structure and costs
- Trick: Right trade-off between size and quality



a) complete network



b) relaxed network



c) refined network

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Trends in Airline Optimization

- Opportunities of technology push environment (and resulting competitive challenges)
  - Extend the problem scope
  - Aim for exact methods in the long term
- Support of end-users and business experts
  - Make use of optimization more “easy”
  - Provide better visualization of data and solutions
  - Support better problem understanding
- Hybrid methods
  - E.g. integration of Mathematical Programming and Constraint Programming
- Focus on the business problem
  - Solve the right problem (which might change constantly)
  - Solutions do not need to be perfect

Personal Thoughts

- The implementation of optimization systems needs to be complemented by change management
  - Process changes
  - Shortening of planning cycles
  - Evolvement of user profiles (e.g. planner **à** analyst)
- Data quality and consistency is crucial
  - "Garbage in, garbage out"
  - All systems should have the same "view" of the operation
- Integration capability with evolving IT infrastructures
  - Gradual replacement of legacy systems
- Optimization projects are also **software engineering projects**

Carmen's Vision

1991: Carmen Crew Planning first production

2000-2002: Descartes project

2004: Carmen-MIT KPI-project starts

2005: ~25% of crew worldwide scheduled by Carmen

2003: Northwest and Delta sign

1988: Carmen signs first contract

1998: 75% of EU crew scheduled by Carmen

2002: Product for Planning and Operations

2008: "Airline-in-a-box" – integrated planning and operations software from Carmen is replacing current legacy

1991

2001

2011

Thank you! Questions?

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http://carmensystems.com