Optimization for Logistics

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Insight

What we want to show

- Optimization problems are everywhere
- But come in very different sizes and shapes
- Need good enough data to be meaningful
- Things go badly wrong if you ignore optimization
- Show steps from fundamental research to actual use

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The Insight SFI Centre for Data Analytics

Insight Overview

4 Co-Lead Universities 9 partner institutions	Built on **20** years of research in Data Analytics and AI
450+ Academics, Postdocs, PhDs, RAs	**3400+** Scientific conference and journal papers
175+ Funded collaborations with industry partners	**350+** Research Awards
16 Spin out companies 72 license agreements	**135+** H2020 consortia, 500+ collaborations, 40+ countries
1,137+ school visits, 28,000 students	**276** PhDs graduated

Insight

The Speaker

- Started 1986 at ECRC in Munich
- Involved in three startup companies
- Imperial College London 2000-2005
- Senior research fellow at UCC since 2008
- Former president of the Association for Constraint Programming (2013&2014)
- Distinguished Service Award of ACP 2022
- Focus on applications of Constraint Programming and Optimization
- Four patents held by Cisco Systems

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A Look at Container Transport

- Most complex world-wide transport system
- Look at five optimization problems
- From global scale to filling individual containers
- Different usage scenarios
  - Amount of information available
  - Accuracy of data
  - Time available to make decisions

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Major Trade Routes

- Container trade flows quadrupled since 1995
- Flows between major areas are not balanced
- Results in large flows of empty containers
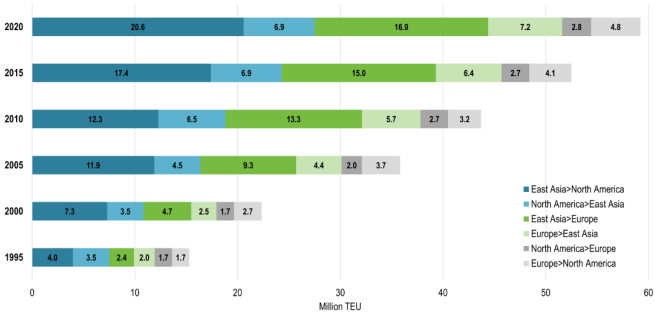
Containerized Cargo Flows along Major Trade Routes, 1995-2020

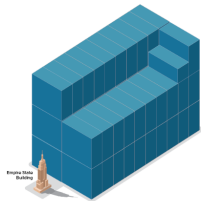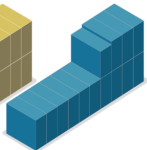*Source: UNCTAD, Review of Maritime Transport.*

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Container Movements 2017

(Source: https://www.visualcapitalist.com/global-shipping-container-traffic/)
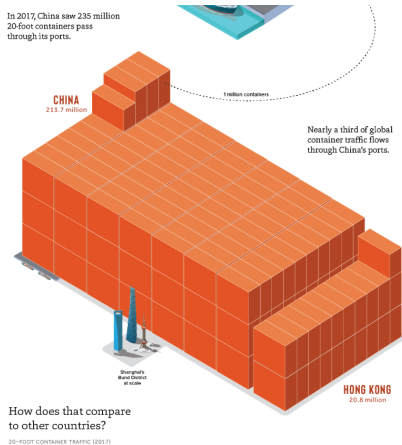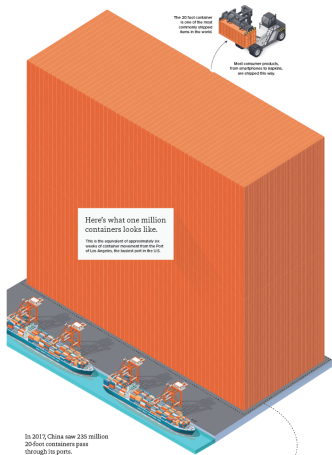
Container Movements 2017 (Ireland: 1m)

20-FOOT CONTAINER TRAFFIC (2017)

UNITED STATES
51.4 million

SINGAPORE
33.6 million
Despite having a population of only 5.6 million people, Singapore moves the third most container traffic in the world.

Empire State Building

JAPAN
21.9 million

GERMANY
19.4 million

NETHERLANDS
13.9 million
Only 15 years ago, the Port of Rotterdam was the world's busiest port. It has since been surpassed by seven ports in China alone.

INDIA
13.3 million

UNITED KINGDOM
10.5 million

AUSTRALIA
7.7 million

PANAMA
6.9 million

MEXICO
6.3 million

CANADA
6.3 million

RUSSIA
4.5 million

NEW ZEALAND
3.2 million

SWEDEN
1.6 million

KENYA
1.2 million

ICELAND
0.3 million
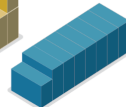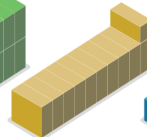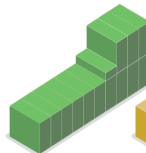
SYRIA
0.1 million
Container traffic prior to the war in Syria (2010)

D.R.C.
0.06 million

visualcapitalist.com

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Back in 2019

- Globalization: Produce where it is cheapest
- Dealing with increasing demand on transport
- Growing ship sizes
- Externalizing costs
- Few mega-ports dealing with huge traffic volumes
- Same time: Massive environmental impact of global shipping

Source: Alphaliner https://slideplayer.com/slide/3441192/
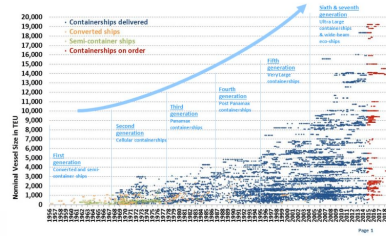
Maritime transport accounts for 3.5% to 4% of all climate change emissions, primarily carbon dioxide. According to the World Bank, in 2022, the shipping industry's 3% of global greenhouse gas emissions make it "the sixth largest greenhouse gas emitter worldwide, ranking between Japan and Germany."

Source: Wikipedia

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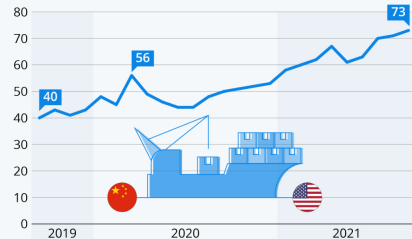
And then things went horribly wrong
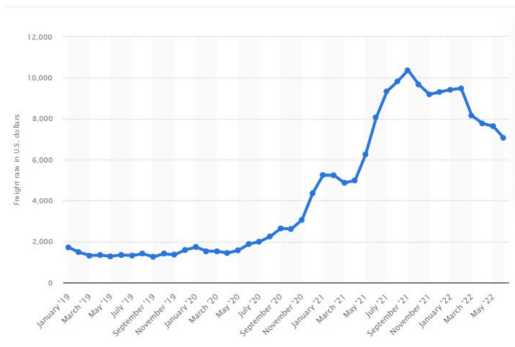
Global container freight rate index from January 2019 to June 2022 (in US dollars)
Image: Statista

Lost in Transit: Major Delays Plague China-U.S. Shipping

End-to-end transit time for China-U.S. ocean freight (in days)

Source: Freightos

Global Container Transport

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Problem: Network Design

- Use which type of ships to connect which ports
- How frequent a connection
- How fast to travel between ports
- How many round-trips per year possible
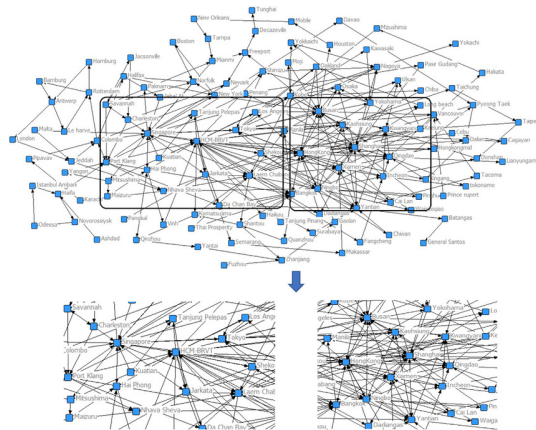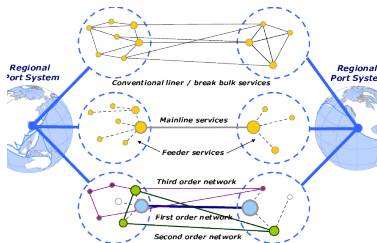
Source: [14]

Source: Port connections in Vietnam [13]

Global Container Transport

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Properties

- Strategic decision making
- Support management, not make decisions
- Uncertain about costs, rates and volumes
- Influenced by decisions of competition/partners
- Rarely a green-field design, incremental updates
- Re-run infrequently, not time limited
- Must deal with uncertainty in results
- Quite similar to airline network design problems

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Result: Ever Alot (Evergreen Line) 24,000 TEU Container Ship

Source: Port of Hamburg

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Problem: Port Operation

- Consists of multiple, connected problems
- Ship berthing
- Quayside crane allocation
- Stacking location
- ASC operations
- Landside pickup (truck and train)
- Often solved in sequence
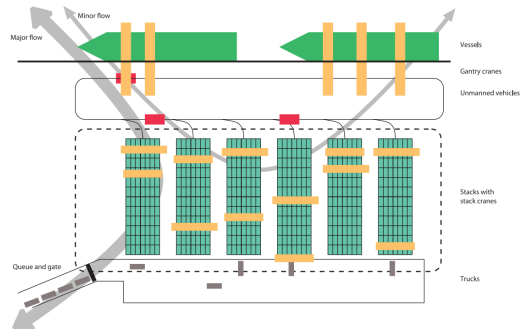
Source: ERCIM News 68 [3]

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A Blast from the Past

- Berth allocation system for HIT in Hong Kong
- Developed in 1988-1989 (ECRC, ICL)
- Very early decision support system with interactive GUI
- Possibly earliest commercial Constraint Programming application
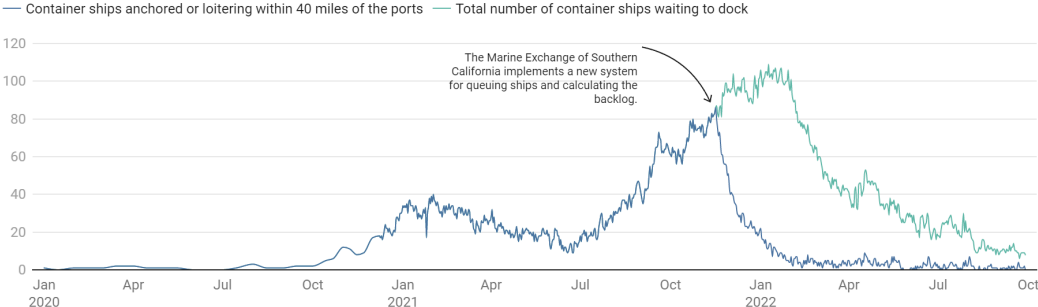- Developed using CHIP/DecisionPower system
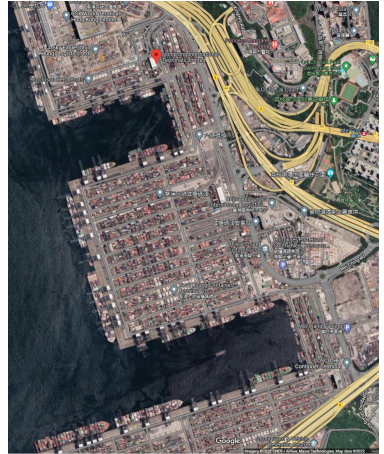
Source: Google Maps, 2022

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Current Trends

- Combine different sub-problems into one more complex optimization problem
- Much more difficult to solve, but allows to find better overall solutions
- Good integration with automated vehicles
- Good visibility of current state
- Data uncertainty rapidly increasing for future
- Continuous replanning required

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When things go wrong: Port of Los Angeles/Long Beach 2021

— Container ships anchored or loitering within 40 miles of the ports — Total number of container ships waiting to dock

The Marine Exchange of Southern California implements a new system for queuing ships and calculating the backlog.

Note: Counts between Dec. 29, 2021, and Jan. 8, 2022, were recorded at 7 a.m. Pacific time. All subsequent counts occurred at noon Pacific time.

Chart: Dylan Miettinen • Source: Marine Exchange of Southern California • Get the data • Created with Datawrapper

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Problem: Traffic Management

- So much traffic, so little space
- Some areas are bottlenecks for global traffic
  - Need traffic management to avoid accidents
- Large ships can only enter/leave harbour at high tide
- Throughput is limited
- One way restrictions at certain points
- Stop loading to make departure time slot
- Move pilots between ships

Source: https://www.vesselfinder.com/

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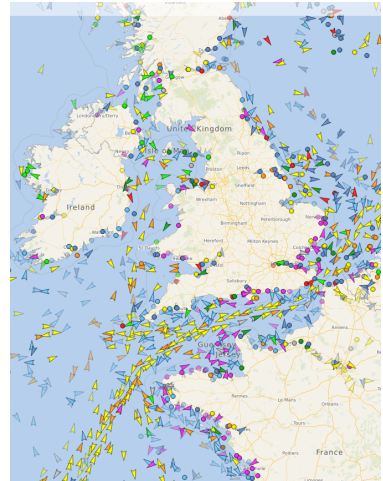
Example: Singapore Strait

- Use optimization to predict hazard situations
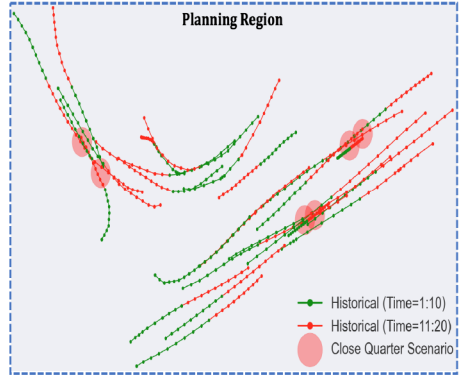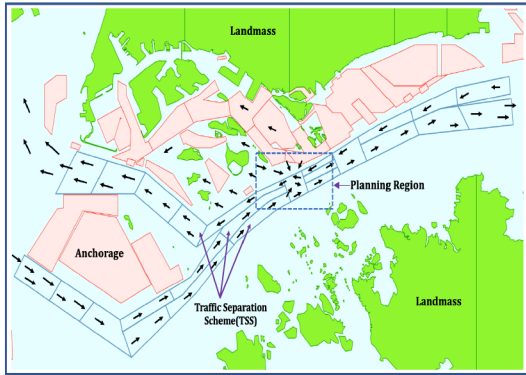
Source: [4]

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Ship Loading

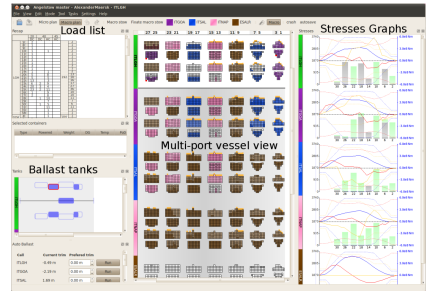- Decide where to place containers in ship
- Pickup/delivery order in stack
- Weight at bottom
- Reefer connection access
- Dangerous goods separation
- Protecting valuable cargo
- Balancing ship at each stage of trip
- Avoid shuffling of containers
- Hard constraints on loading time, leave cargo behind

From: A constraint programming approach to capacity planning in container vessels
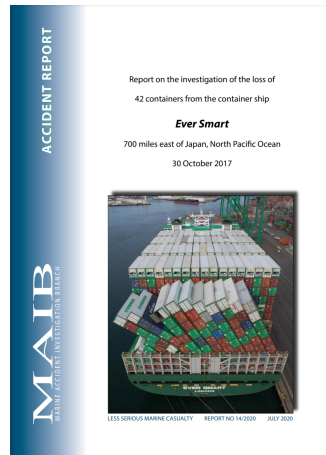
Insight
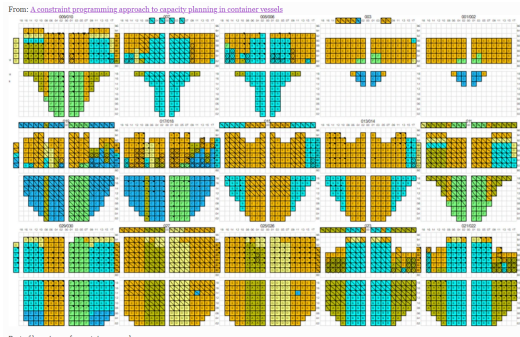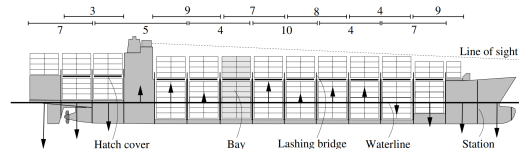
Current State

- Many different problem variants
- Very different solution methods
- Commercial solutions
- Problem keeps getting harder, as ships grow in size
- No consensus on problem formulation

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When you do not use your optimization tool

- Ever Smart (7,024 TEU) in 2017 lost 42 containers in stormy weather
- Evergreen Line, then fourth largest shipping line worldwide
- On route from China to US
- Loss not noticed at the time
- Root cause: Not stacked according to rules
- Likely caused by time pressure at port
- Source: Accident Report https://assets.publishing.service.gov.uk/
  media/5f15a2993a6f405c0f80ac37/2020-14-EverSmart-withAnnexes.pdf

ACCIDENT REPORT

Report on the investigation of the loss of
42 containers from the container ship

Ever Smart

700 miles east of Japan, North Pacific Ocean
30 October 2017

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

LESS SERIOUS MARINE CASUALTY   REPORT NO 14/2020   JULY 2020

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Data Issues: Weight Discrepancies

- Business rule: weight is declared by shipper, not checked by carrier
- Remaining containers weighed after accident
- 30% differ from declared weight
- Loading computer forced into making bad decisions
- Still, loading program knew that loading was not safe

Global Container Transport

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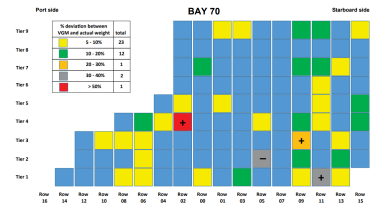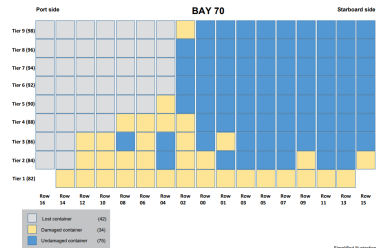
Recent Increase in Container Losses

- Published numbers (WSC) are disputed
- No current legal requirement to announce container losses
  - Except for dangerous goods
- Largest recent event: 1,800 containers from ONE Apus, Nov 2020
  - Estimated Damage: 200m USD
  - No accident report published yet
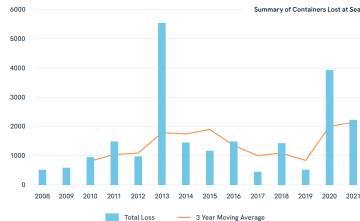
Summary of Containers Lost at Sea

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Problem: Container/Truck Loading

- How to best use space inside containers
- 3D packing problem
- Accessibility constraints
- Balancing issues
- Special case: Pallet loading
- Special case: Irregular shapes

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Competition Euro/Roadef2022

- Run by European/French OR societies
- 2022 event sponsored by Renault
- Transport items from suppliers to factories
- Truck cost/inventory cost
- Packing problem at core
- Scale: 260,000 items, 5,000 trucks
- Results expected in 2023/2024
- More at `https://www.roadef.org/challenge/2022/en/index.php`

Insight
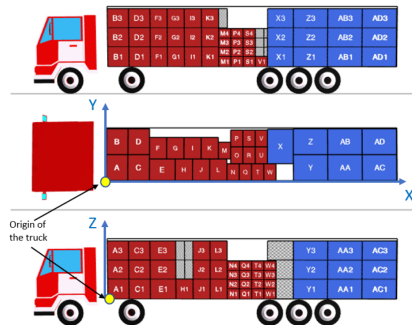
On-going/Future Disruptions

- Driver shortage
  - Ireland: 3,000-4,000
  - UK: 70,000-100,000 (Source RHA)
  - EU: 425,000 (Source IRU)
  - USA: 80,000 (Source ATA)
- Self-driving trucks
  - Initial automation of only part of trips likely
  - "Last mile" human delivery
  - Needs a very different optimization solution
- Climate change

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Climate Change Impact Example

- During Summer 2022, water level in Rhine river sank to record lows
- Pegel Kaub: Below 1m from 14/7 to 21/8, minimum 0.32m on 15/8
- Major bulk transport shut down nearly completely
- Dramatic increase in low-water surcharges
- Knock-on effect on other transport modes
- Major impact on energy supply in time of crisis
- Table Source: Maersk Rhine River Low Water Surcharge 2020

Tageswerte der Wasserstände am Pegel in Kaub aus der Pegeldatenbank der WSV im Jahresverlauf seit 1970
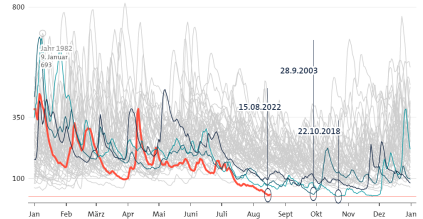
Grafik: SWRdata • Quelle: Wasserstraßen- und Schifffahrtsverwaltung des Bundes (WSV), bereitgestellt durch die Bundesanstalt für Gewässerkunde (BfG)

Surcharge (applies to laden container only)

Measuring Pegel KAUB*	20'	40'
< 1,51m	EUR 30	EUR 40
< 1,31m	EUR 45	EUR 60
< 1,11m	EUR 60	EUR 75
< 1,01m	EUR 75	EUR 100
< 0,91m	EUR 100	EUR 135
< 0,81m	EUR 175	EUR 225
< 0,71m	EUR 240	EUR 300
< 0,61m	EUR 320	EUR 425
< 0,51m	EUR 475	EUR 625
< 0,41m	EUR 600	EUR 775
< 0,31m	EUR 775	EUR 950

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Travelling Repair Person (TRP)

- Providing service for devices at customer premises
- Planned preventive maintenance and testing, regular visits
- Technicians travel to multiple, but few customers per day
- Unplanned repair work after faults, response-time critical
- Service times quite variable
- Impact of skills and local knowledge

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Compared to Other Service Planning Problems

- Stationary technician, moving customers
  - Example: car tune-up
  - Preventive, planned work
  - Either a queuing or scheduling problem
- Moving customer, moving technician
  - Road side assistance
  - Reactive, unplanned work
  - On-line dispatching, pre-positioning
- Moving technician, stationary customers
  - Example: cable installation, photocopier repair
  - Mainly reactive, sometimes planned work as well
  - Routing and scheduling aspects

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Why is this important? (1)

Law and Crime

Lift firm Otis fined HK$320,000 over Hong Kong mall escalator accident that injured 18

Company, which pleaded guilty to four summonses, could have discovered safety issues with escalator three months before malfunction, court told

Jasmine Siu
Published: 8:15pm, 9 Mar, 2018

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Why is this important? (2)

BIG STORY 10   APRIL 5, 2016 / 6:40 AM / 3 YEARS AGO

Schindler sells Japanese business to Otis after accident

2 MIN READ

ZURICH (Reuters) - Elevator maker Schindler is selling its Japanese business to United Technologies' Otis unit after its new installations in the country were halted following a 2006 accident.

Source: REUTERS

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Why is this important? (3)

Elevator at one of Chicago's tallest skyscrapers plunges 84 floors after hoist rope breaks

NOVEMBER 19, 2018 / 10:47 AM / CBS NEWS

Source: By Chris6d - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=78201640

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TRP Compared to Other Combinatorial Problems

Bin Packing

balanced workload

Clustering

compact work areas

Travelling Repair Person

minimize travel

Vehicle Routing Problem

due dates interrupted work

(Pre-emptive) Scheduling

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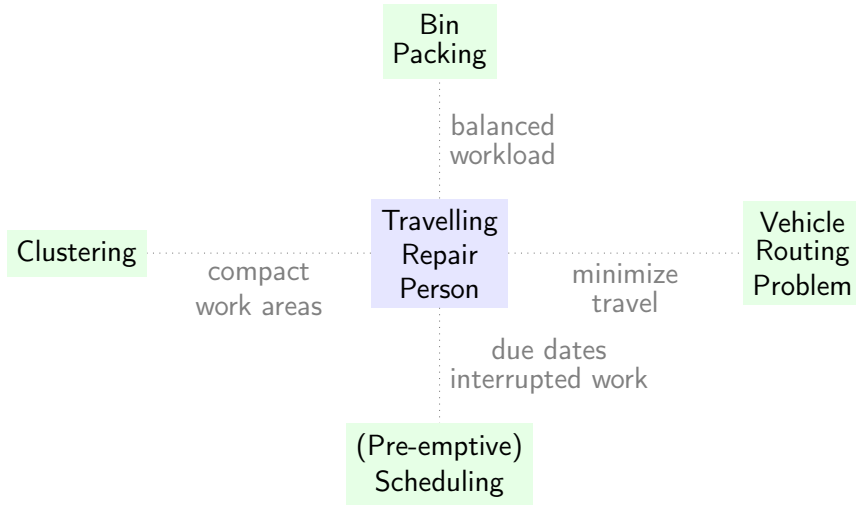
TRP - Interesting Research Problem

- Combines elements of multiple combinatorial problems
- Hard constraints, multiple cost elements
- Stochastic events are core part of problem

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Key Research Challenge

- Use combination of Optimization and Simulation to model and solve the TRP
- Optimization
  - Good for global cost model
  - Detailed constraints of problem
  - (-) Does not easily deal with unplanned work
- Simulation
  - Good for modelling individual actors
  - Understanding impact of stochastic changes
  - (-) No global view of problem

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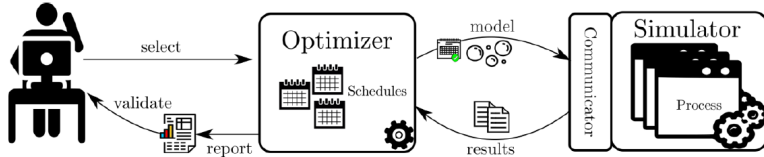
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High-level View

Figure 1 High level overview of the framework

- Optimizer deals with planning, load balancing, efficient schedules
- Simulator explores how to react to changes
- Simulator also provides one result as assumed reality

Optimizer Design

- Infeasible to build homogenuous model for complete problem
- Added business process constraint
  - Technicians should be responsible for "their" buildings
  - Improves service quality
  - Customers see familiar face
- All work in one building should be performed by the same engineer, if possible
- Engineers should be assigned compact areas of work
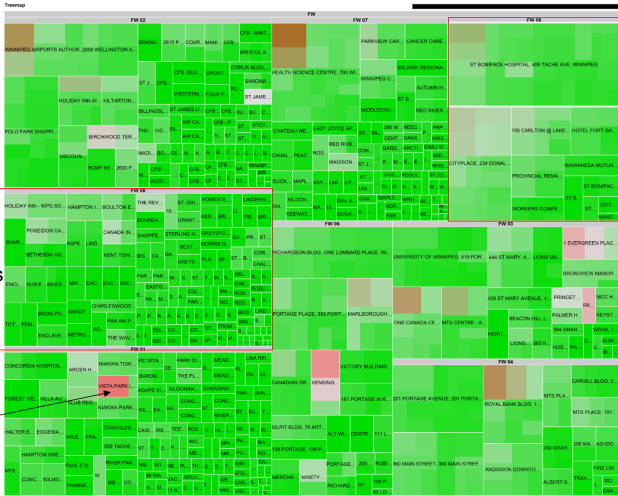- Balanced workload within the same depot

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Clustering and Depot Assignment

Routes and Trips

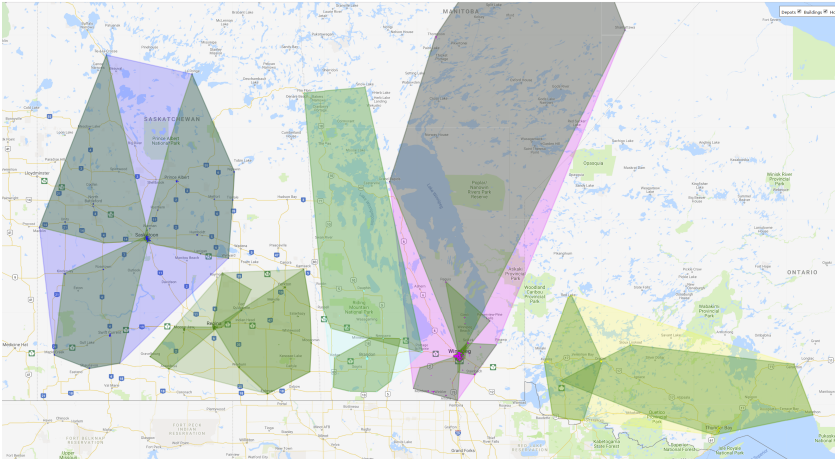Insight
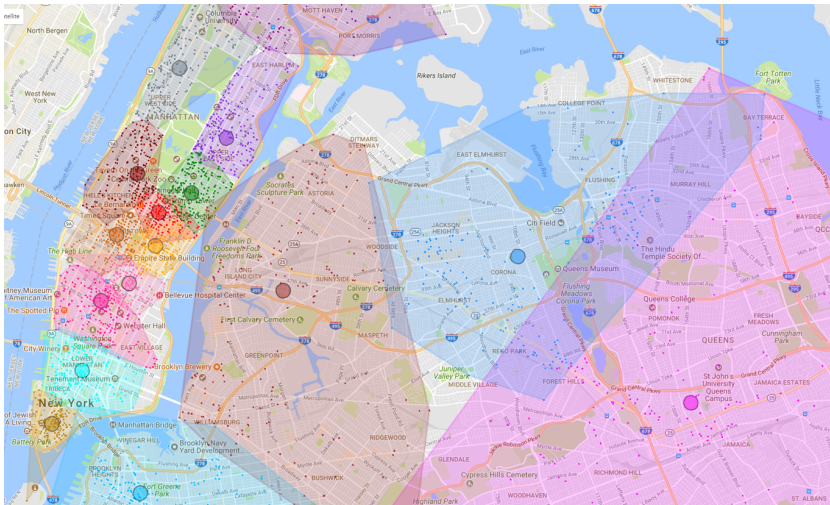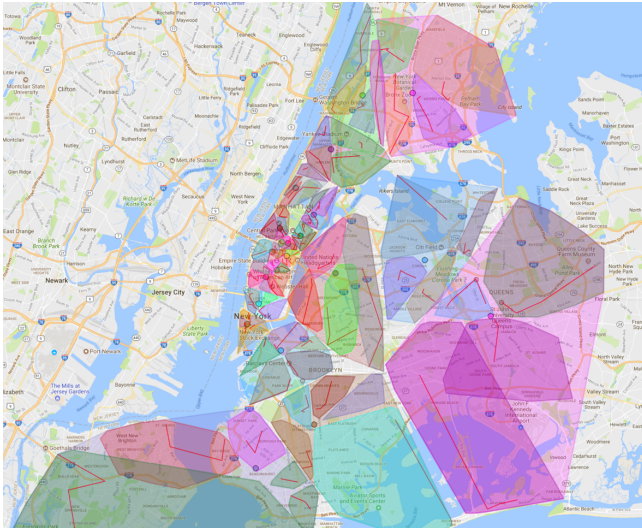
Actual Data: Workload and Callbacks as Treemap

Very few, but large buildings
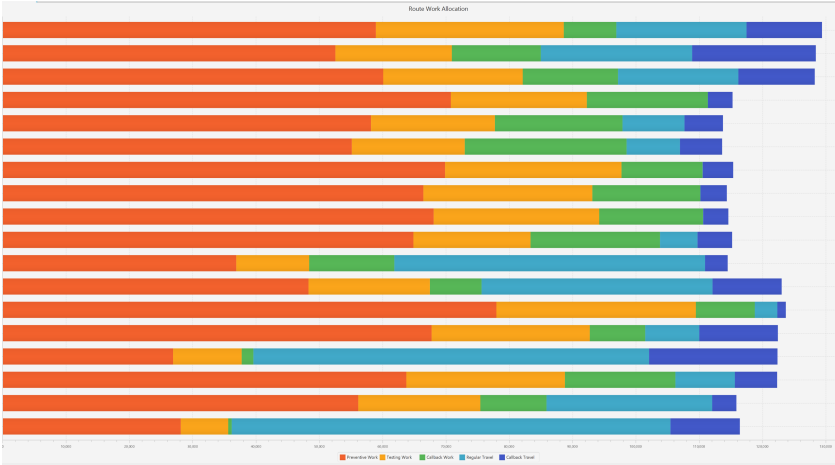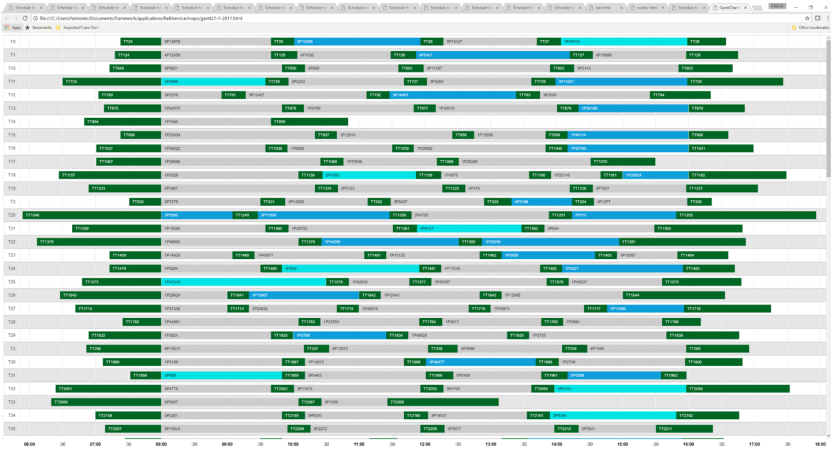
Many small buildings

Colour indicates yearly call-backs

Scheduling Service Visits

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Actual Data: Mix of Urban and Rural Customers

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Actual Data: Balancing Workload Within Depots

Route Work Allocation

Legend: Preventive Work, Testing Work, Callback Work, Regular Travel, Callback Travel

Scheduling Service Visits

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Scheduling: One Day of Monthly Plan

Scheduling Service Visits

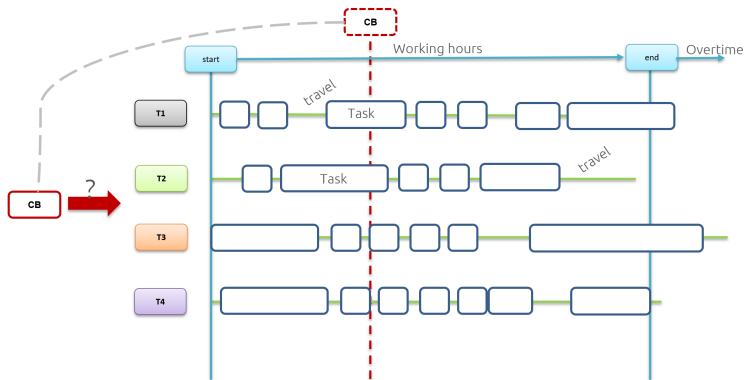Insight

Simulator Process Modelling
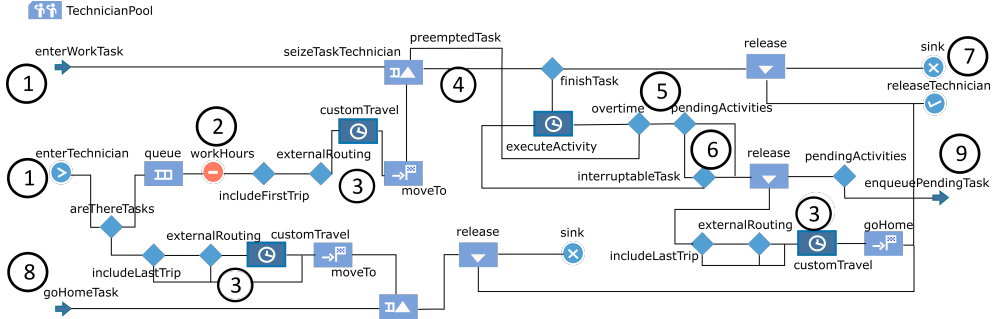
Dealing with Unplanned Callbacks

- Who is dealing with the callback?
- How to adjust the schedule after callback?

Challenges: Tools and Results

- We provide research and experimental software
- **Not** a solution
- End-user would like applicable results
- Managing expectations is important
- Multiple joint publications
- Technology transfer at end of project

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Problem: Car Transport

- Deliver cars from import ports/factories to dealers
- Also fleet management (car hire, government)
- Delivered by special car transporters
- Via compounds (possible work at workshop)
- Example of downstream logistics

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Working with NVD

- Total yearly volume 320,000 cars and trucks

NVD Rosslare

NVD Baldonnell

NVD Ringaskiddy

Transport

- Port to Compound
- Factory to Compound
- Nationwide ex Compound
- Nationwide - Dealer to Dealer

Storage
75 hectares of secure storage
Capacity to hold 35,500 units
- Baldonnell, Co. Dublin *(13,500 units)*
- Ringaskiddy, Co. Cork *(10,000 units)*
- Rosslare, Co. Wexford *(12,000 units)*

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Properties

- Highly seasonal
- Very specialized equipment
- No/little backhaul
- One day ahead planning
  - Changing, added orders
  - Dialog with customers

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What Makes this Problem Special?

- Loading cars on transporters
- Using hydraulic platforms to shift/lift cars
- Deep domain knowledge
- Often possible to load one/two more cars
- More skills required
- How to teach computer what can/cannot be done?

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Global Car Distribution

- By train, in many countries, not in Ireland
- By special car transport ships
- In containers (some manufacturers only)

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Multiple Steps from Research to Fielded Application

1. First contact during ESGI-128 study week, 2017
2. Consulting contract to define problem, 2019
3. Experimental implementation
4. First comparison runs against manual schedule, 2019
5. Start-up creation by NVD
6. Second stage algorithm tuning, 2020
7. Support start-up team while application live, 2021

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Challenges

- Data quality: collected data not cleaned for machine use
  - Example: Addresses good enough for driver, not good enough for GraphHopper
- Telematics data not accessible
- Conflicting views on objectives by different stakeholders
- No agreed-on cost model
- Solutions for peak demand period not acceptable in low-demand period
- Hidden preferences for selecting/avoiding some roads

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Remaining Research Challenge: Explanations

- Human planners would sometimes question automated solution
- Why did it do this, instead of that?
- Significant effort required by developer to answer these questions
- Can this be automated/generalized?

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Car Transport - A Risky Business

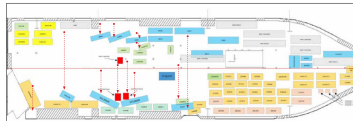SERIOUS MARINE CASUALTY   REPORT NO 6/2016   MARCH 2016

Figure 15: Deck 6 - original stowage and direction of shift of displaced cargo

Figure 16: Track-type bulldozer; original stowage position on port side and final resting position to starboard

MV Golden Ray, Sep 2019

MV Felicity Ace, Feb 2022

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The Classical Problem

- Your process needs many components to be bought in
- Different suppliers over subsets of items at different prices
- Volume discounts depend on different criteria for each suppliers
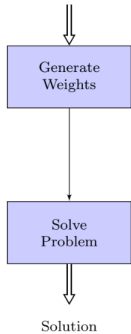- Which suppliers to select to get best deal?

Our Work

- Cost is not the only selection criterion
- Promised lead times vary between potential suppliers
- On-time delivery makes a huge difference
- Keep supplier set small to build working relations
- How do you weigh different objectives

Insight

Approach

- Active Learning
- Interact with user to compare solutions

(a) State-of-the-art approach
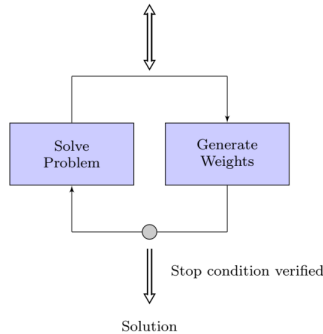
(b) The proposed approach

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Insight

Optimization is Everywhere

- We have shown several specific case studies
- Completely ignored other aspects of Logistics
  - Inventory control
  - Warehouse management
  - Transportation
  - Scheduling
- Very active research areas for Insight/Confirm

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Upcoming Event

**Insight@UCC Event: "The Science of Better'
Nov 10 with Dell Technologies**

- More info at https://www.insight-centre.org/ucc-event-the-science-of-better-nov-10-with-dell-technologies/

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Insight

Shipmap Visualization

- Visualization of Global Ship Movements
- Created by University College London, Environmental Institute
- Based on transponder data from 2012
- More info: `https://www.vox.com/2016/4/25/11503152/shipping-routes-map`
- Map: `https://www.shipmap.org/`

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Book: Marc Levinson - The Box, Princeton University Press, 2006

- Very readable history of the container
- Changes in ports between 1950-1980
- Interaction between
  - carriers
  - shippers
  - ports
  - unions
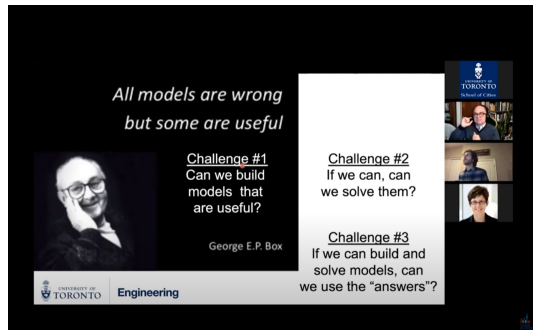 - government
- US centric view

Insight
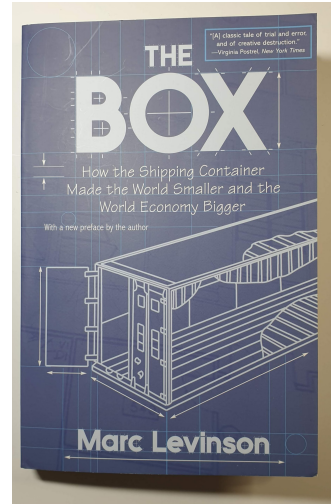
Video: Why Global Supply Chains May Never be the Same

- A WSJ Documentary
- March 2022, 54 minutes
- Good look at situation in US
- Impact on ports, hauliers, warehouses
- Youtube comment: "WSJ did a great job of putting human faces on all this."
- https://youtu.be/1KtTAb9Tl6E

Insight
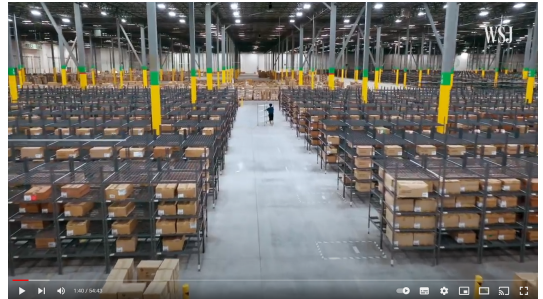
Video: Supply Chain Optimization: An Operations Research Perspective

- Prof. Chris Beck, Univ. Toronto, Canada
- Jan 2021, 56 minutes
- Different perspective
- https://youtu.be/yYxM7x65704

Insight

Mark Antunes, Vincent Armant, Kenneth N. Brown, Daniel A. Desmond, Guillaume Escamocher, Anne-Marie George, Diarmuid Grimes, Mike O'Keeffe, Yiqing Lin, Barry O'Sullivan, Cemalettin Ozturk, Luis Quesada, Mohamed Siala, Helmut Simonis, and Nic Wilson.
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