IFORS TRIENNIAL CONFERENCE

QUEBEC - JULY 2017

OR PRACTICE MATTERS

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UNIVERSIDAD DE CHILE

IFORS
International Federation of Operational Research Societies

INGENIERIA INDUSTRIAL
UNIVERSIDAD DE CHILE

ISCI
Instituto Sistemas Complejos de Ingeniería

How importance is **PRACTICE** in OR?

- **Journals: Few practice papers**
- **Many applications carried outside Academia, little incentive to publish**
- **Top universities give more weight to methodology**

How would **OR** look if there was no relation to the **real world**?

- **BUT Operations Research DOES**
- **Look at journals such as EJOR, INTERFACES, OR PRACTICE and others.**
- **Look at competitions on applied OR projects:**
  - **INFORMS EDELMAN**
  - **EURO PRACTICE AWARD**
  - **IFORS OR IN DEVELOPMENT**
- **So there is an effort to give significance to OR practice.**

And there are multiple areas where OR has played a **very significant role**

- **Airlines: Revenue Management, Scheduling of fleet, and crews.**
- **Transportation and Logistics: Vehicle routing, fleet design.**
- **Supply Chain.**
- **Production Planning**
- **Health at different levels.**
- **FEDEX, UPS**

Want to show specific work **our group** has carried out

- More than present several cases, they belong to a story, a narrative of OR in Chile and our group.
- Chile (as the rest of Latin America) is weak in R&D.
- Chile spends 0.5% of GDP on R&D, more developed economies spend 2% to 3%.
- Industry carries out little research in areas where Chile plays an important role in the world:
  - Copper, Salmon Industry, Timber and Pulp Industry
- Few OR PhD's in Industry

- Lack of high level professionals in industry presents us with a challenge, a duty and an opportunity.
- Engineering professionals (6 year career) and master graduates are of high quality
- In many sectors managers have realized the opportunities OR can provide to improve productivity, even quality of life.
- This as led to very significant collaboration between our group and industry.

INSTITUTE FOR COMPLEX ENGINEERING SYSTEMS (**ISCI**)

- **We are a small group.**
- **Good financial backing via a large grant.**
- **Different areas complementing OR:**
  - **Data Science, Consumer analytics, Transportation, Industrial Organization, Energy, etc.**
- **Overall 60 researchers, 15 member staff.**
- **We cover an arc from methodology to applications**
- **Projects with impact and innovative, leading to publications**

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Rank applied OR papers developed by **Interfaces**

U. de Chile Score 34.0 N° 1

Non-U.S. Universities	Int	Int C	M&SOM	M&SOM C	OR	Score	Rank
University of Chile	29	0	0	0	5	34.0	1
University of Toronto	8	1	0	0	1	9.5	2
Norwegian University of Science and Technology	6	0	0	0	0	6.0	3
Lancaster University	5	0	0	0	0	5.0	4
Cass Business School	0	8	0	0	0	4.0	5
Laval University	4	0	0	0	0	4.0	5
Miguel Hernández University	4	0	0	0	0	4.0	5
University of Buenos Aires	4	0	0	0	0	4.0	5

Georgia Institute of Technology Score 25.5

U.S. Universities	Int	Int C	M&SOM	M&SOM C	OR	Score	Rank
Georgia Institute of Technology	22	3	0	0	2	25.5	1
Naval Postgraduate School	22	3	0	0	0	23.5	2
Colorado School of Mines	8	13	0	0	0	14.5	3
Carnegie Mellon University	9	1	0	0	2	11.5	4
United States Military Academy	11	0	0	0	0	11.0	5
Purdue University	8	0	0	0	2	10.0	6
Boston University	9	0	0	0	0	9.0	7
University of Cincinnati	7	4	0	0	0	9.0	7
University of Southern California	8	0	0	0	1	9.0	7
MIT	6	3	0	0	1	8.5	10
University of Maryland, College Park	7	3	0	0	0	8.5	10
Lehigh University	6	0	0	0	2	8.0	12
Villanova University	7	2	0	0	0	8.0	12
Stanford University	5	0	2	0	0	7.0	14
University of Dayton	6	2	0	0	0	7.0	14
North Carolina State University	3	7	0	0	0	6.5	16
University of California, Los Angeles	1	1	0	0	5	6.5	16

We **hope** to…

- **Change the way the firms operate**
- **Establish long term relations with industry**
- **Most systems are still in use, between 10 to 25 years**

NOT EASY, PROBLEMS CHANGE, MANAGEMENT CHANGES, FIRMS CHANGE

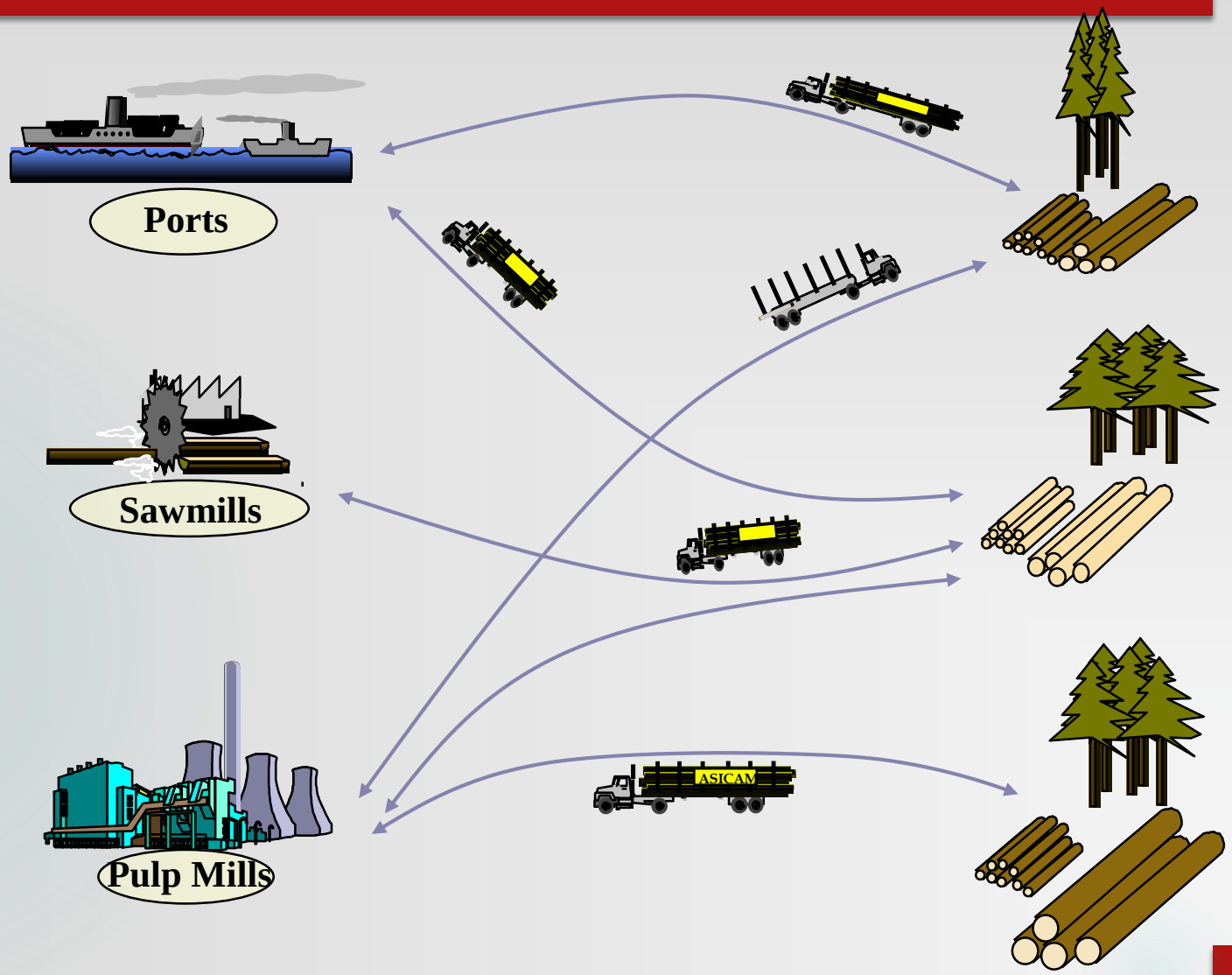
FOREST TRANSPORTATION

1990

We started around **1990**

- Forest Industry collaborated with Fundación Chile sharing technologically improvements such as introduction of advanced harvesting machinery.
- One problem all forest firms had was in transporting logs from multiple points in the forest to destinations such as pulp plants, sawmills and ports.
- Transportation constitutes 40% of operational costs

ASICAM: System Description



Before we arrived…

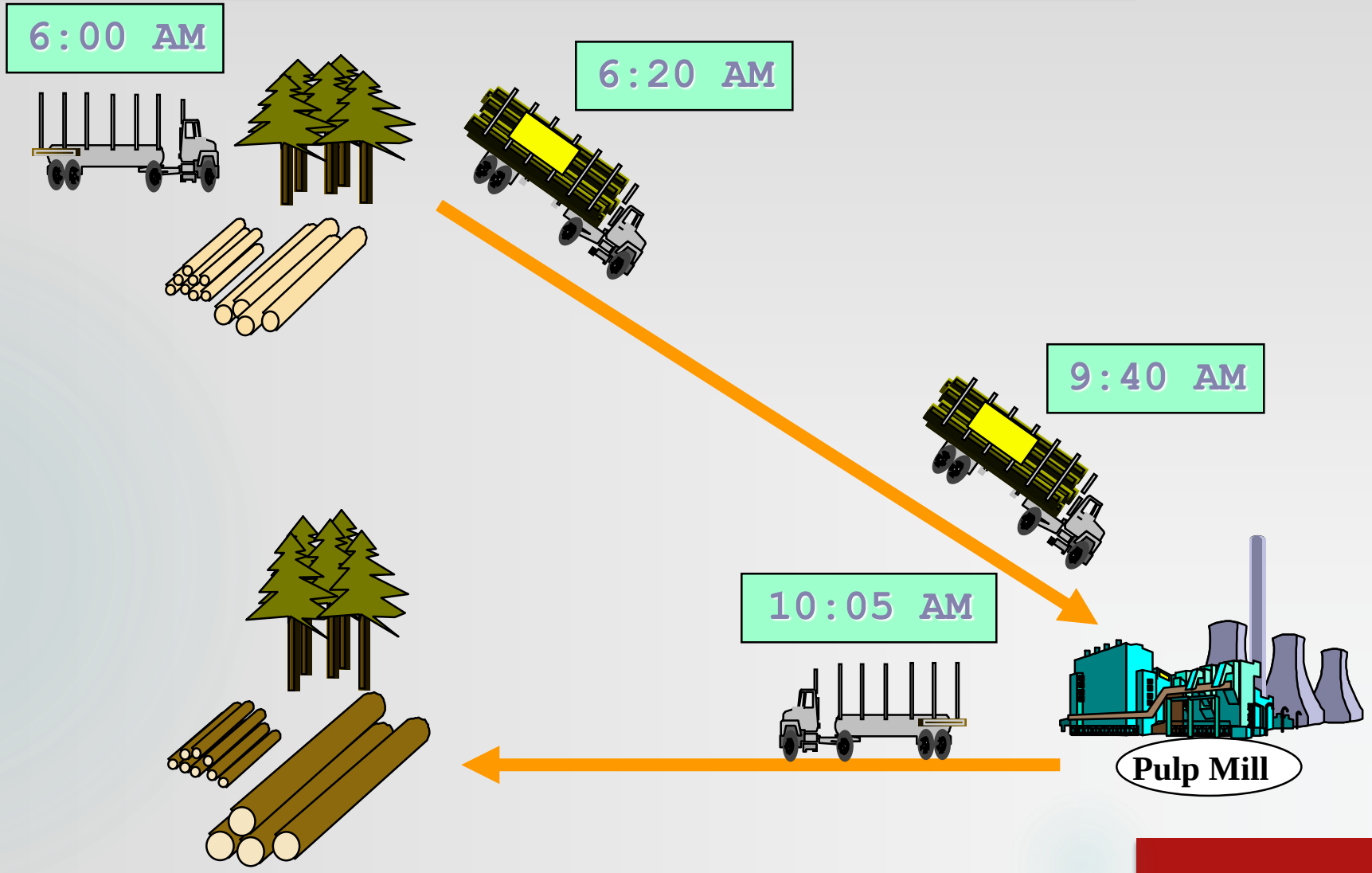
- **Forest firms scheduled trips manually:**
  - **Significant losses in efficiency**
  - **Too many trucks**
  - **Long queues**
  - **Not being able to satisfy scheduled deliveries**
- **We were invited to develop a system to support truck scheduling:**

ASICAM

ASICAM

- Is a daily scheduling system
- Based on a deterministic simulation model with heuristic rules
  - Do not send trucks to a loader if there will be several trucks ahead of it.
- Simulation carried out in a moving horizon along the day.

ASICAM



ASICAM **benefits** and **impact 1998**

- **Savings:**
  - Reduced truck fleet and loaders by 30% each.
  - Annual savings between 15% to 25%.
- **Organizational:**
  - Better downstream coordination
  - Less queues: Work hours reduced from 14 to 11
  - Driver's salaries improved
  - Easier management of complex system

Later...

- We developed additional systems to support:
  - Short, medium and long term harvest planning
  - Location of harvesting machinery
- These systems won the EDELMAN AWARD 1998

MINING

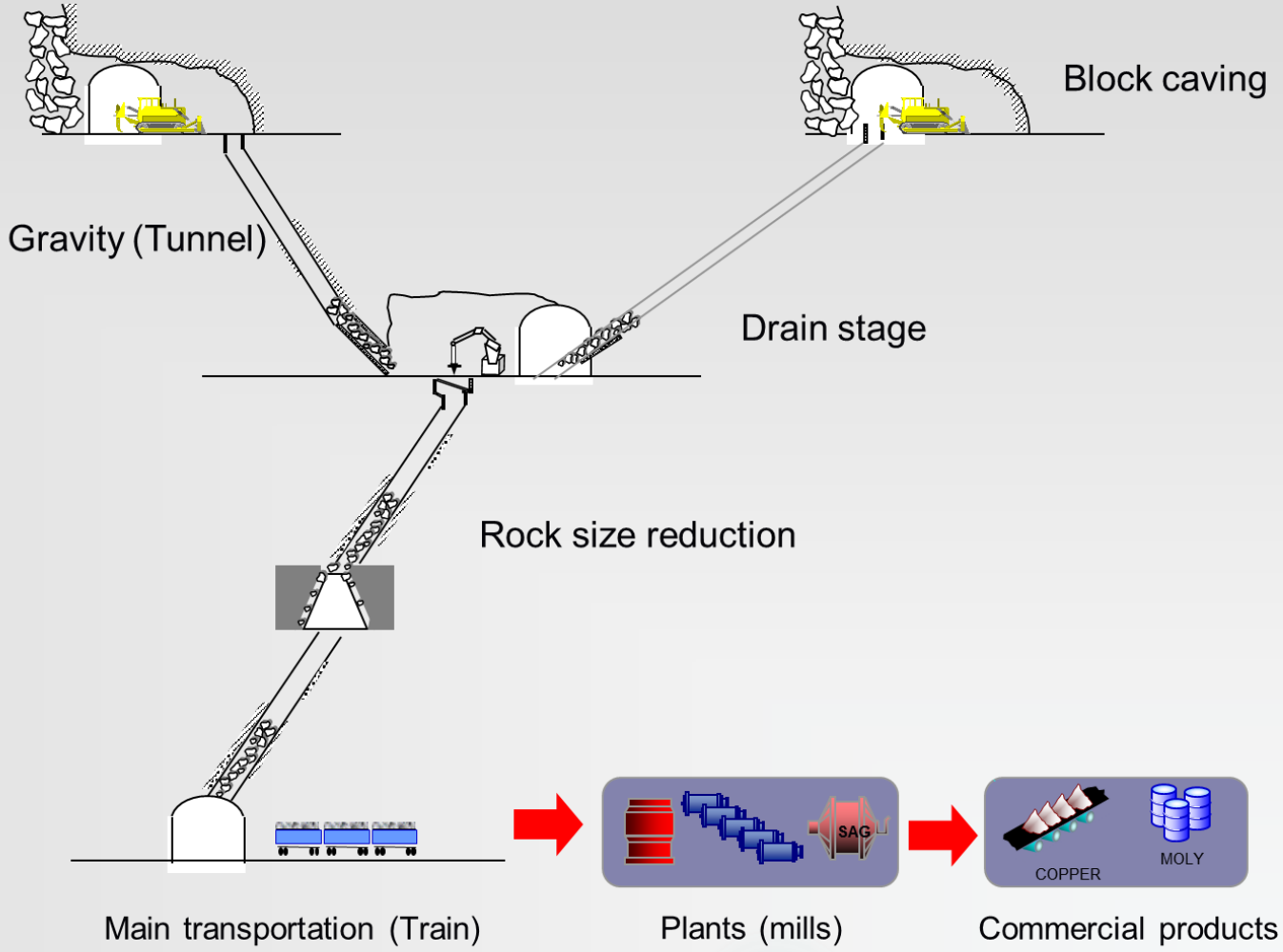
1997

In the late **90's**

- Based in part by success in forestry start work with CODELCO.
  - The largest copper firm in the world.
  - State owned, run independently.
- Problem: Planning extraction
- Two types of mines
  - Underground
  - Open Pit

Underground Mine: **El Teniente**

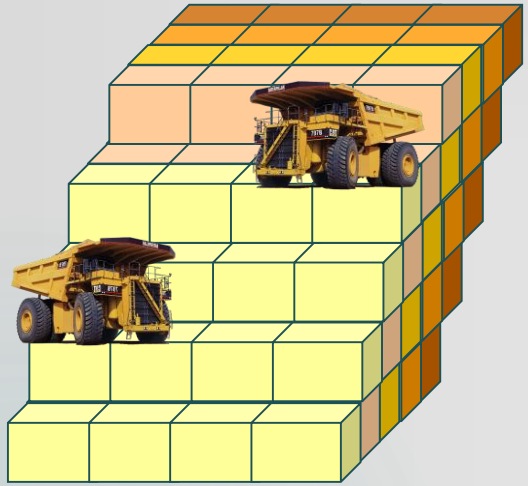
- El Teniente uses block caving (rock breaks and falls through gravity)
- Columns enter in sequence
- Mechanical constraints
  - Max extraction rate (roof collapse)

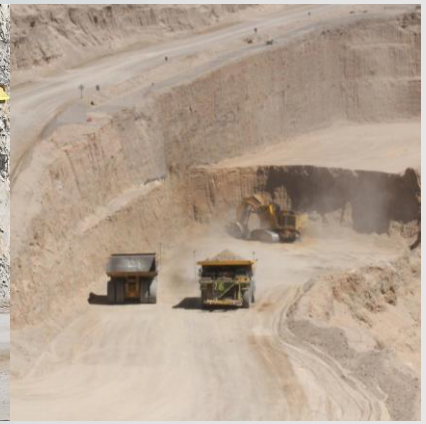


Underground Model

- Model needs to decide:
  - Which sequence of columns. When to extract from each column
  - How far up to go in each column before going to the next one. (Grade goes down as we go up the column, never come back)

Open pit: **Chuquicamata**

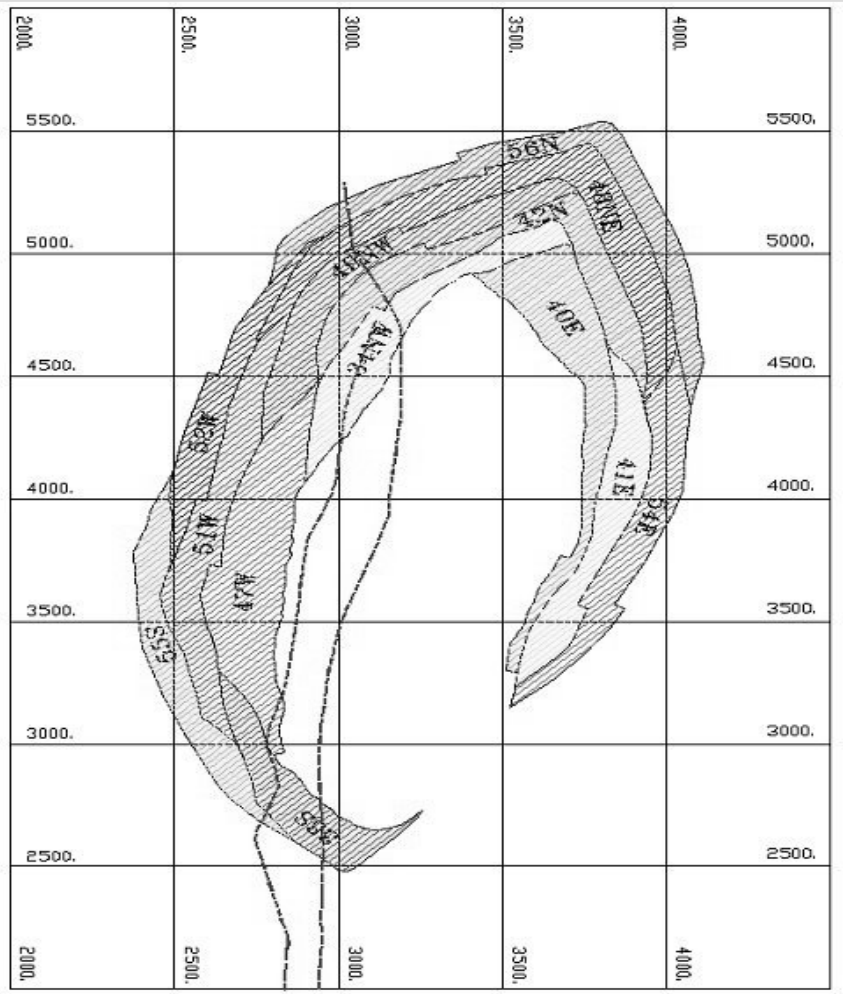




- One of the largest open pit copper mines in the world
- The hole is expanded via explosions. Create benches/roads
- Extraction of copper ore or waste
- Material is moved using VERY large trucks (300 tons).

Open pit Model

- Previously used approximate models
- Advances hardware and software
- MIP Multicommodity model of the production chain from mine to final refined copper.
- The mine is divided into hundreds of thousands blocks 30x30x30 meters.
- Decisions:
  - Sequencing of expansions and benches
  - Investment in equipment and trucks
  - Destination of material from each bench



Open Pit Model

- **Minimize cost considering:**
  - **Mass conservation**
  - **Capacities**
  - **Angle of slope**
  - **Logical Constraints (to extract a block, all above it need to be extracted)**
  - **Environmental constraints (Arsenic)**

Impacts and benefits

- Extraction cost savings
  - El Teniente 5%
  - Chuquicamata 8.2%
  - Used in other CODELCO mines, overall a yearly savings above US$ 100 million

  (As shown in Epstein, R., Goic, M., Weintraub, A., Catalán, J., Santibáñez, P., Urrutia, R., & Caro, F., Optimizing long-term production plans in underground and open-pit copper mines: Operations Research, 2012)
- Being used in regular planning and *what-if* decisions.
  - Postpone several years Chuquicamata going underground
  - Mayor investments, like a new refining plant
  - Implementing new metallurgical processes

CONTAINER LOGISTICS

2005

Back in **2005**

- In 2005 CSAV called us to support decisions on how to handle their 500.000 container fleet
- CSAV handles shipping though leased containers of different types along 700 ports divided into seven regions
- Clients ship merchandise on containers between ports
- Empty containers need to be returned to areas of higher demand (China) Example: New York to Shanghai

Containers: types

- There is transport intra regions and between regions
- The company felt it was not managing well the positioning of the empty containers, in particular had too much inventory in each port
- We developed **ECO**: **E**mpty **C**ontainers Logistics **O**ptimization

Dry Van 20 ft

Dry Van 40 ft

Flat Rack 20 ft

Flat Rack 40 ft

Open Top 20 ft

Reefer 40 ft

Project **Challenges**

- There are several challenges in developing analytics to handle this problem:
  - Uncertainty including demand for empty containers in each port
  - Data handling (400.000 container transactions per day)
  - How to coordinate decisions between all regions

The system: **ECO**

ECO Includes:

- Demand forecast model
- Inventory model, safety stocks for each port, each container type
- Multicommodity Network Flow Model (some integer variables) to define movements of containers (1.2 Million variables, 600.000 constraints)
- WEB interface to allow intervention of regional managers (local knowledge in demand, events)

- System 24/7, runs every 8 hours to plan on a horizon of 180 days
  - Leasing and returning containers
  - Safety stocks
  - Shipping empty containers

Implementation history

2006: Project Start

2007: Prototype in Chile & Brazil

Financial crisis

2008: Global Prototype Validation

2009: Global Implementation Plan

Jan 2010: ECO Goes Live

Impact

- Savings in 2010: 80 Million dollars (half of the profit that year)
- **EDELMAN 2011** finalist
- CSAV merged with Hapag-Lloyd in 2014 and system was abandoned

THE FRANZ EDELMAN AWARD
Achievement in Operations Research

SCHOOL MEALS

1998

JUNAEB: Meals for schools

- **JUNAEB, The National Corporation of School Support and Fellowships, depends on the Ministry of Education**
- **Provides 1.5 Million daily meals to public schools**
- **Cost of 600 Million US.**
- **The service is provided by about 30 private firms which bid every year**

JUNAEB
Ministerio de Educación
Gobierno de Chile

The Challenge

- Chile is divided into 300 territorial units and firms compete to provide the service to all schools in each territorial unit

- Firms can make bids on different combinations of units and menus. Thus, each firm can propose hundreds of different bids

- JUNAEB needs to choose a combination of bids that will cover all units, with acceptable menus at least cost

Back in **1998**

- **Before 1998 this task was done manually (Excel) with many drawbacks**
- **Need to choose between 25.000 bids in 72 hours after opening the bids**
- **In 1998 Rafael Epstein and his team developed a combinatorial auctions model**
- **Strengthened MIP, need to solve hundreds of alternative models in 36 hours consider:**
  - **At least two firms per unit**
  - **Give advantage to firms with good previous performance**
  - **Options for menus**

Impact: Change the industry

- The first year of use (1998) the new system led to savings of 40 Million US first year over total cost of 150 Million US
- In addition, the competition compelled firms to improve their processes and thus, change the industry
- The system won the **IFORS** prize in the competition OR in Development in 2002

Junaeb

IFORS
PRIZE FOR OR IN DEVELOPMENT

Spin-off

- System still in use, with new improvements along the years
- The team has developed a logistic system for distribution of 17 Million textbooks to 10.000 schools

FIREFIGHTERS

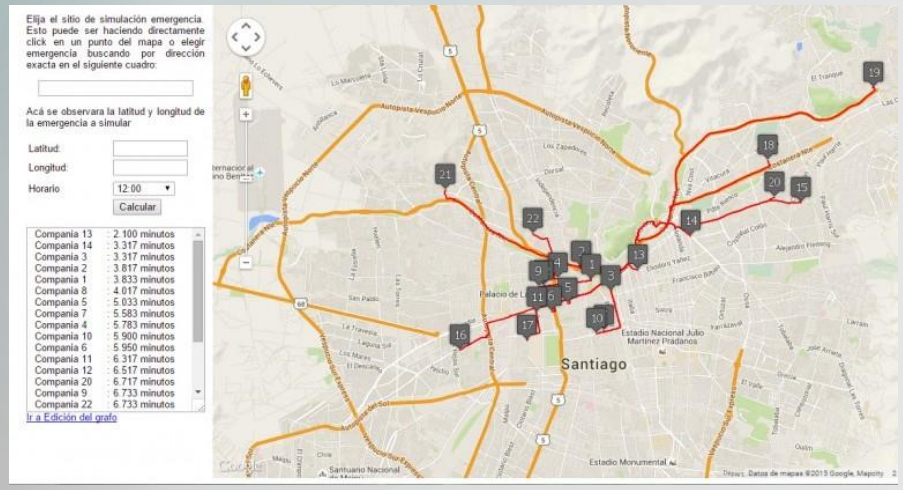
2013

Getting fast to fire is vital: "**OR on fire**"

- Fernando Ordonez developed a system, used by firefighters in Santiago, to decide on which station will send the fire trucks to a fire and by which route
- Project started in 2013
  - Implemented in 2015
- Solution in SECONDS
- Need to arrive before 4 minutes

The solution: **Commander**

- **The system is based on defining a set of shortest paths from possible fire locations to fire stations, using Dijkstra algorithm.**
  - **Traffic data based on GPS on buses**
  - **Travel times, other speeds estimated by experts based on traffic profiles**
  - **Actualized measuring actual travel times of fire trucks**



SOCCER SCHEDULING

2004

Scheduling of Chilean Soccer
Leagues and Conmebol Qualifiers

This is a story about soccer...

Our passion...

World's passion...

Scheduling Chilean Soccer leagues

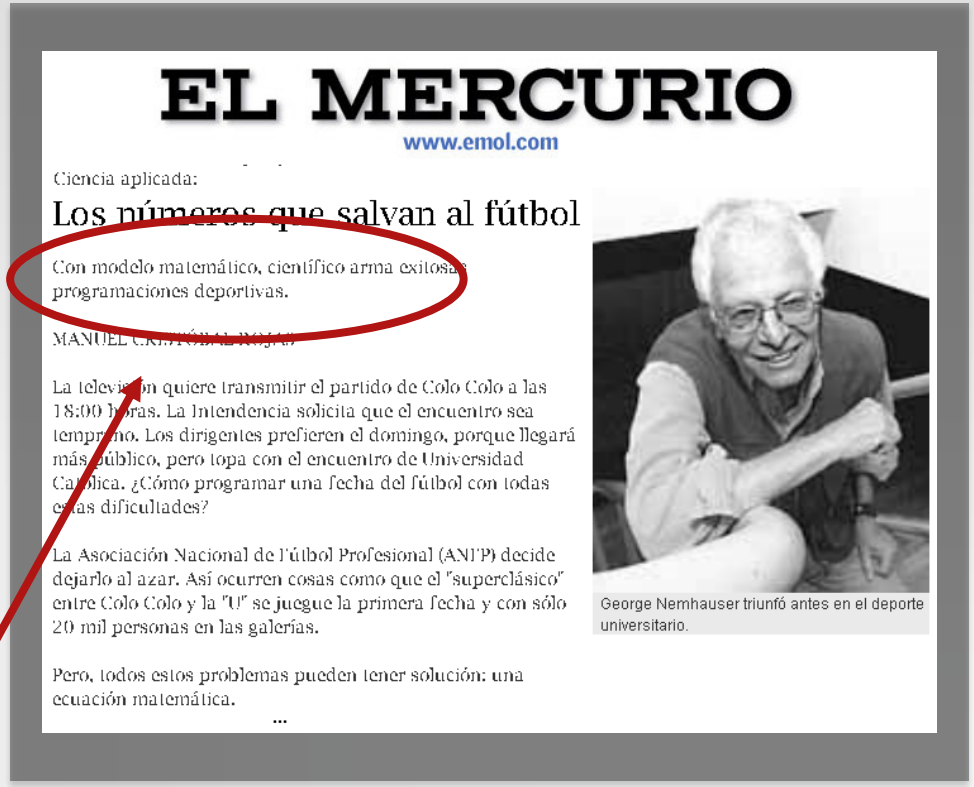
- Soccer leagues play round robin tournaments (every team against every other). The team with most points at the end wins the tournament (some few cases with play offs)

- Scheduling who plays each week is difficult, billions of combinations.

- Tournaments in most leagues schedule basically in a random model, leads to poor scheduling:
  - Best games at wrong dates
  - Conflicts with TV
  - Poor coordination with international tournaments

Everything started in **2004**

- A visit by George Nemhauser showed how he and Mike Trick schedule the baseball season in the US.
- Presented the idea to the Chilean national Futbol federation.
- Developed for the 2005 season and been in use since.



EL MERCURIO

www.emol.com

Ciencia aplicada:

Los números que salvan al fútbol

Con modelo matemático, científico arma exitosas programaciones deportivas.

MANUEL [illegible]

La televisión quiere transmitir el partido de Colo Colo a las 18:00 horas. La Intendencia solicita que el encuentro sea temprano. Los dirigentes prefieren el domingo, porque llegará más público, pero topa con el encuentro de Universidad Católica. ¿Cómo programar una fecha del fútbol con todas estas dificultades?

La Asociación Nacional de Fútbol Profesional (ANFP) decide dejarlo al azar. Así ocurren cosas como que el "superclásico" entre Colo Colo y la "U" se juegue la primera fecha y con sólo 20 mil personas en las galerías.

Pero, todos estos problemas pueden tener solución: una ecuación matemática.

...

George Nemhauser triunfó antes en el deporte universitario.

"By using a mathematical model, scientist generates successful sport schedules"

Aligning different **Stakeholders**

Government

Police

Players Union

TV

International calendar

Fans

Team's representative

ANFP TODO POR EL FUTBOL

FEDERACION DE FUTBOL DE CHILE

Operations Research

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Schedule

FIRST ROUND July 15			SECOND ROUND July 22		
U. ESPAÑOLA	-	COLO COLO	O'HIGGINS	-	U. DE CHILE
D. IQUIQUE	-	U. CATOLICA	HUACHIPATO	-	D. IQUIQUE
S. WANDERERS	-	S.M. ARICA	S.M. ARICA	-	COBRESAL
U. DE CHILE	-	ANTOFAGASTA	U. CATOLICA	-	U. LA CALERA
COBRESAL	-	SAN LUIS	SAN LUIS	-	S. WANDERERS
A. ITALIANO	-	PALESTINO	PALESTINO	-	U. ESPAÑOLA
U. LA CALERA	-	O'HIGGINS	COLO COLO	-	A. ITALIANO
U. DE CONCEPCION	-	HUACHIPATO	ANTOFAGASTA	-	U. DE CONCEPCION

Solution Approach

- Difficult combinatorial problem

The solution approach is based on a two stage scheme:

- In the first stage sequences of home and away patterns are generated for each team through a MIP model
- This is an approximate way to reduce the feasible space for the second stage.

Solution Approach

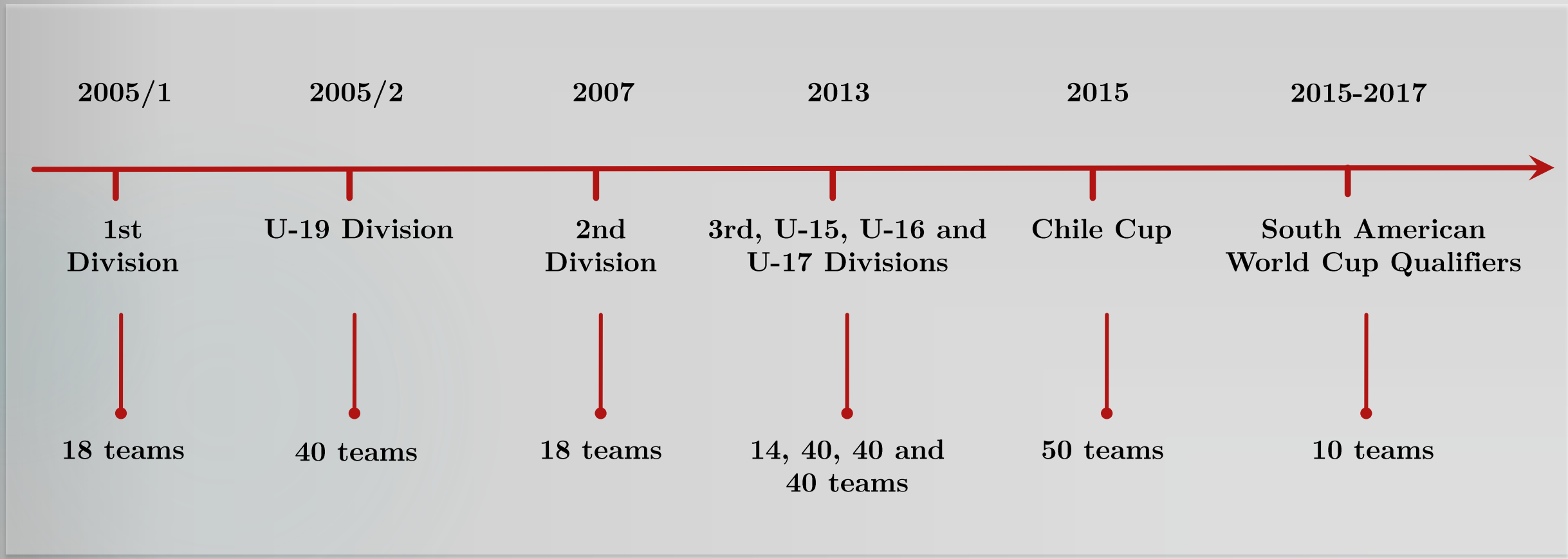
- In the second stage the specific games of each round are determined through a MIP model that incorporates other constraints:
  - Coordinate with International tournaments
  - Classic rival games on selected dates
  - Better travel coordination, minimize consecutive away games
  - Strong teams competing for the championship play more games against each other towards the end of the tournament.

- About 50 runs carried out each year, until federation and teams are satisfied.

Succesful implementation

- Increase Attendance
- Increase Futbol channel subscriptions
- Led to increased income 6 Million US, tickets and TV subscriptions (total income 150 Million)
- Later schedule also second, third division and youth tournaments

Adoption of OR for soccer Scheduling



2018 World Cup South American QF

- Schedule 2018 World Cup South American Qualification Round Robin Tournament in two stages

- Strong Constraints
  - Each two game round, one home one away game
  - Starting as a home game is balanced
  - Mirror Tournament (Chile starts with Brazil in Santiago in the first half, then should start the second half Chile playing Brazil away)

OUR GROUP SHOWED YOU CANNOT HAVE EVERYTHING

Results

- Games are assigned through a MIP with heuristics that satisfies constraints.
- Several countries had proposals, our group's was selected and defined the schedule being played now.

Portability: Basketball and Volleyball

- This approach was extended by Guillermo Duran, leader of the project to two professional sports in Argentina, Basketball and Volleyball

- Mainly to reduce travel distances/times

THE FRANZ EDELMAN AWARD
Achievement in Operations Research

EDELMAN Finalist 2016

OR in **real world**

- Our experience in applying OR to real, important problems has been for us exciting feeling of contribution to firms, institutions, country long term
- Supports teaching our students, who participate in projects
- Ingenio Community with a 5 person team teaches in high-schools

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Some lessons…

Partner with the person in charge

The system is your friend.

Succeed or fail together

Work daily side by side

The initial problem is not the same as the final problem

Do not trust anybody

Do the whole project

Show me the money

Free work is not appreciated

Some Lessons…

Have fun!

OR PRACTICE IS IMPORTANT

HOPEFULLY CAN CHANGE THE WORLD

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