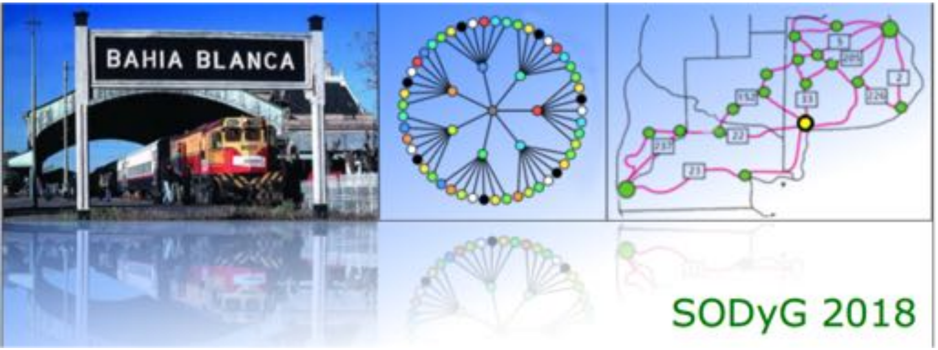

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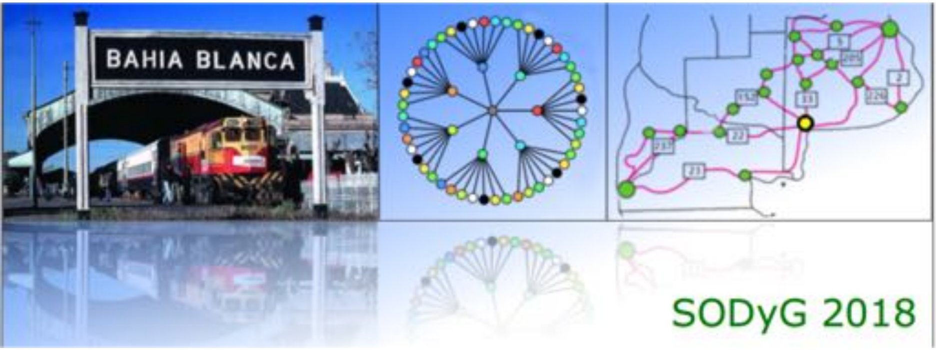
Modelamiento y resolución de un problema real de producción y despacho de concreto en un área urbana

Cristián E. Cortés

Universidad de Chile



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Coauthors:

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Outline

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Motivation and problem description

- This is a real problem of a company that produces, transports and delivers ready-mixed concrete (RMC) to different clients spatially distributed over Santiago city.
- It is the second major distributor of RMC in Chile.
- In the Metropolitan Region (Santiago city and its surroundings), the company has different branch offices splitting the operation in zones with autonomous administration.
- Branch offices receive as inputs their assigned workload from a central administrative area (control tower) located in the most important branch office in Santiago.

Motivation and problem description

- The company produces different types of RMC, which are sold (in M^3 format), scheduled (definition of time windows for client deliveries) and delivered.
- A logistic control and a tracking process are implemented in order to ensure, with high probability, that products are delivered timely, in the required locations and with the proper specifications.

Motivation and problem description

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- **The problem then is the simultaneous assignment of each client requirement to a specific plant, for being produced at certain moment (schedule), and to a specific ready-mixer truck for final dispatch to the corresponding site.**
- We are now implementing a computational system to help the company make decisions at different levels: fleet design (trucks assigned to branch offices, monthly), starting times of truck drivers shifts (weekly), simulating next day operation (including an estimate of request cancellations) and daily assignment (specific request-plant-truck)

EL optimizador puede apoyar en diferentes procesos de decisión, pero es importante tomar definiciones relevantes

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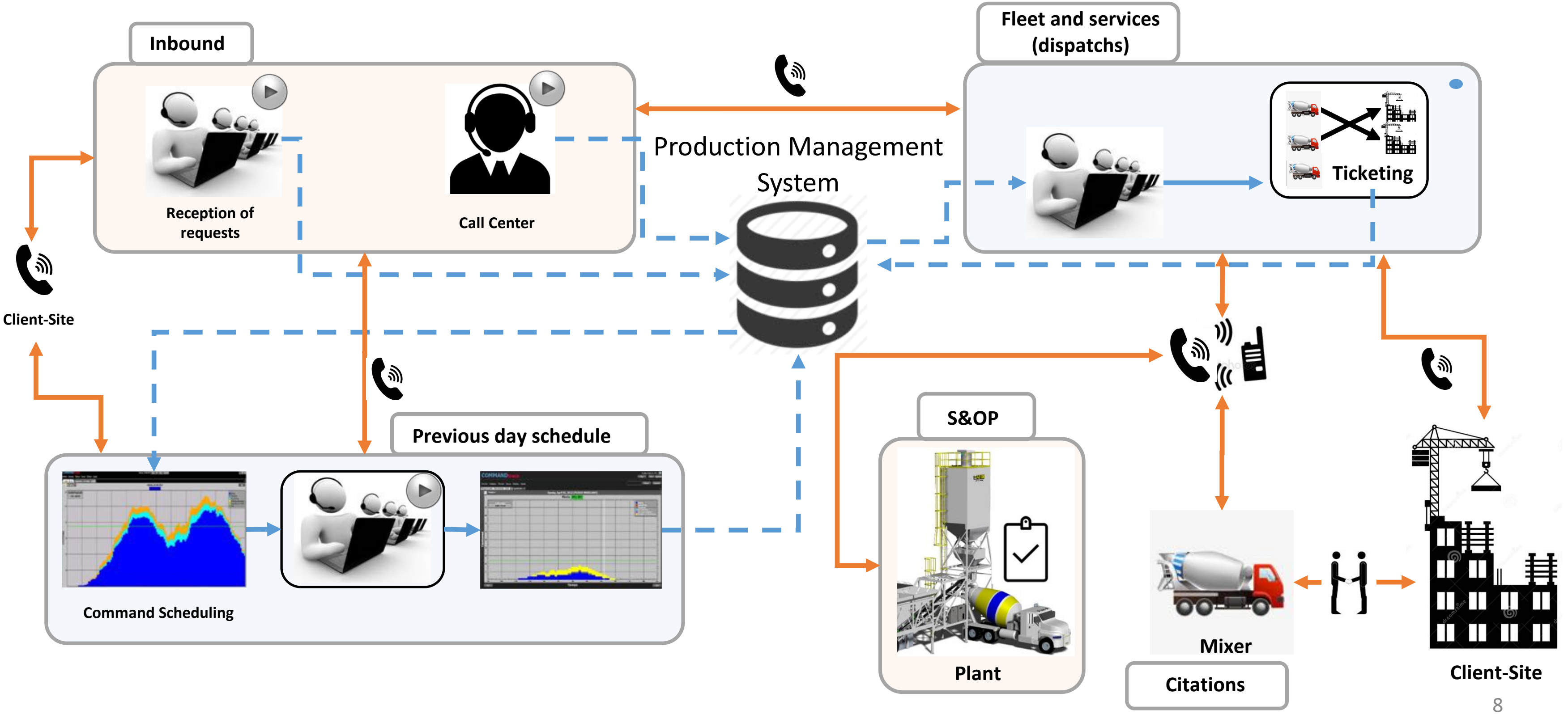
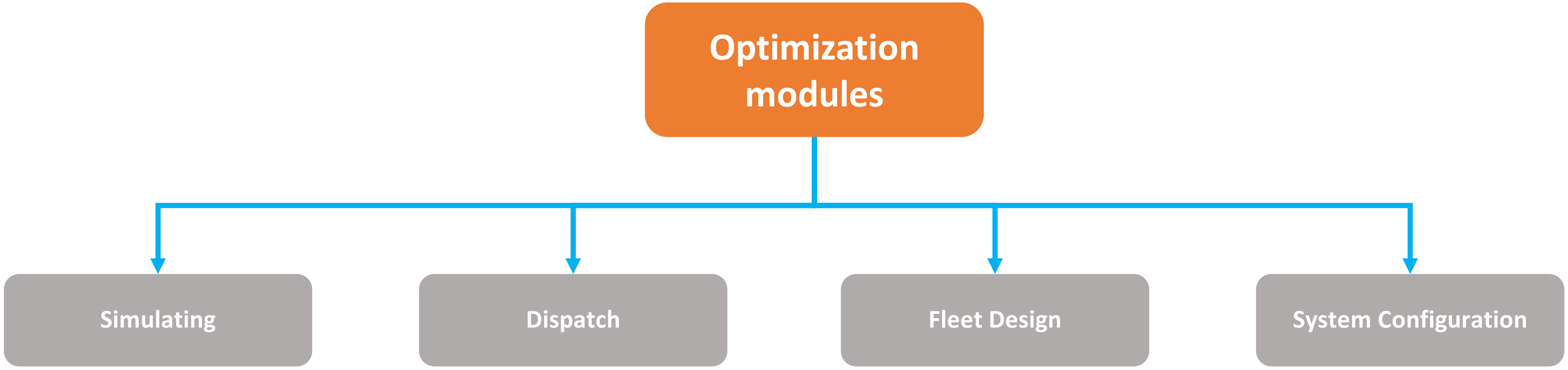
Macro-Proceso de la empresa

Proceso	**S&OP**	**Citación**	**Inbound**	**Programación Fina**	**Despacho**
Frecuencia	Mensual	Semanal/Diaria?		Día anterior	Mismo día
Usuario	Planificación Operacional	Encargado de Planta		Programación Fina	Despacho
Decisión Clave	N Mixers por sucursal	Horario de entrada de los N mixers por sucursal		**Cuadrar oferta demanda:** • Confirmar pedidos • Proyectar cancelación • **Re-asignar plantas a despachos** • Negociar con clientes • **Confirmar escenario**	• **Ticketear** • **Re-asignar plantas** • **Planta de regreso mixer** • Coordinación mixer-obra
Grandes Dudas Negocio		• Hora continua o turnos acotados de entrada • Repetir perfil de entrada semana	• Programa pedidos 10 m3?		• Mixer regresa a otra suc? (tarifa, contratos, etc) • Política colación • Mecanismo valoración clientes
Outputs Posibles Optimizador	N "óptimo" por sucursal (dada dda proyectada)	• N "óptimo" por horario de entrada (continuo o bloque) por sucursal (dada dda ingresada jueves)		• Puntualidad esperada por sucursal y bloque horario (dada demanda bruta, con y sin cancelación esperada) • Escribe en Command nueva reasignación de planta a pedidos? (al "guardar escenario")	• Sugerir ticketeo/ticketear • Sugerir/cambiar planta a pedido • Sugerir /cambiar sucursal de regreso de mixer

Current Process Diagram of Control Tower



Design tree of Optimization modules



	Simulating	Dispatch	Fleet Design	System Configuration
Focus	Optimization for a future day (or past) under different scenarios, scheduling plants optimally	Dynamic optimization of ticketing, rescheduling of plants and interchanges	Strategic design of fleet (e.g. monthly) Tactical design of shifts (e.g. Citation times for next week)	Global configuration of parameters (cancellation patterns, default values, $ per minute of delay, etc)
Users(*)	• Control tower • Future scheduling • Others (tactical and strategic design)	• Control tower-Dispatch	• Logistic area	

(*) current configuration

Outline

1. Motivation and problem description
2. **Literature review**
3. Data analysis
4. Development of solution algorithm
5. Results
6. Conclusions and ongoing research

Literature review

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- **Feng and Wu (2006):** advanced modeling of multidepot ready-mixed concrete with homogeneous fleet. Many variables and constraints are defined, resulting in a hard model to be solved for real cases. It is solved by a combination of GA and a dispatch simulator.
- **Asbach et al. (2009):** model that considers multiple depots and homogeneous fleet. The model is simplified, although the number of variables increases as there is no distinction between clients and deliveries. Real instance is solved through local search heuristics from a first solution where clients are assigned to plants with an insertion method.
- **Maghrebi et al. (2014):** simplified case for a single depot and homogeneous fleet. Focused on dispatch only; plant schedule issues are ignored.
- **Maghrebi et al. (2015):** Two heuristics are proposed: Sequential GA constructs a solution based on sequences (schedule and dispatch). Robust-GA generates work slots according to loading capacities and split each client in separated dispatches.

Literature review

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- **Kinable et al. (2014):** split the concrete dispatch in: capacitated routing of trucks and schedule of plants. Problem is solved with heuristics combined with CP.

- **Biruk (2015):** The concrete dispatch is solved through simulations; four processes are identified (loading process, trip from plant to costumer, unloading at costumer site and return trip) and their times are modeled with triangular probability distributions.

- **Misir et al. (2011):** hyper-heuristics combining local search with respect to different neighborhood structures are proposed for solving real instances of scheduling deliveries of ready-mixed concrete.

Outline

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Characterization of Supply in Metropolitan Region

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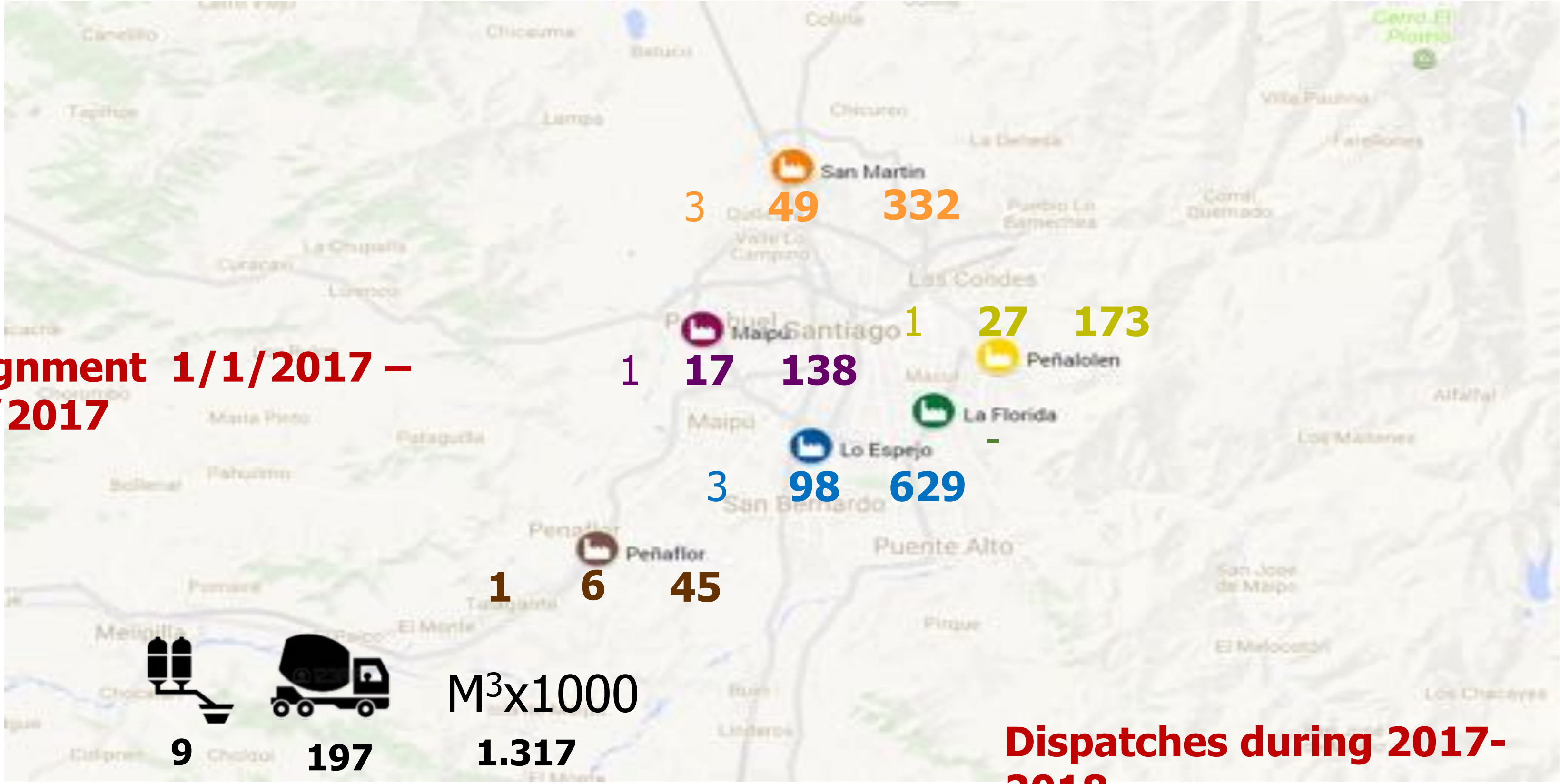
The dispatch of RMC in MR is conducted from 9 plant distributed in 5 branch offices with 197 trucks in total



Assignment 1/1/2017 – 6/6/2017

Dispatches during 2017-2018

Characterization of the Demand in MR

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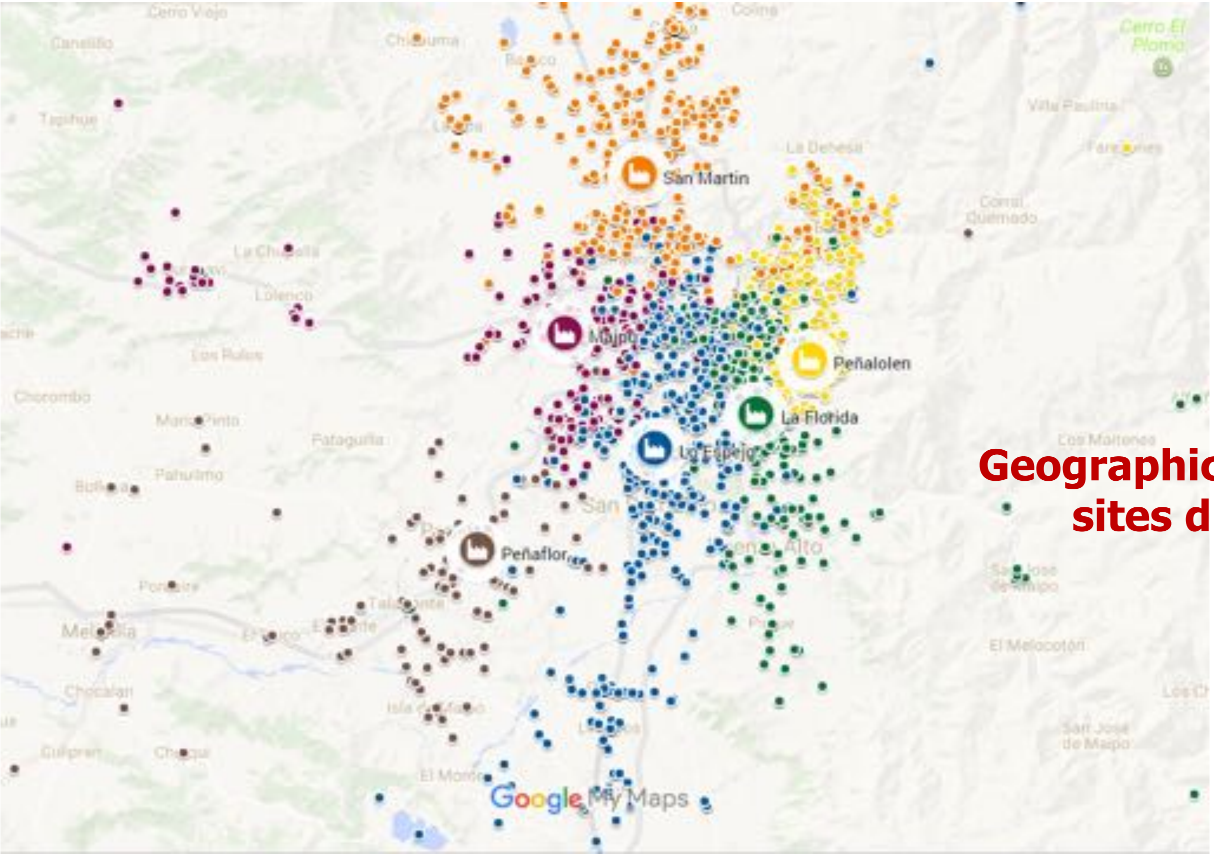
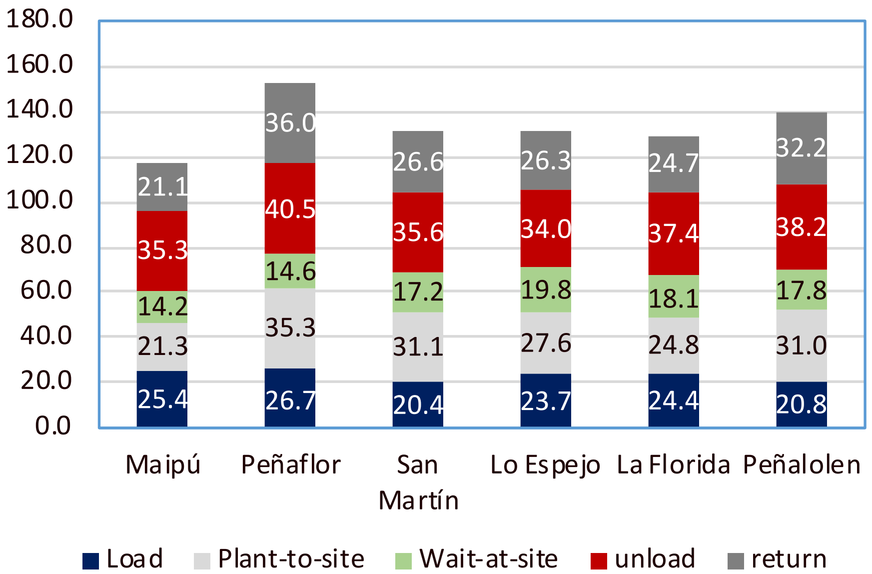
Lo Espejo Branch Office concentrates most of the operation, because the production is the cheapest there



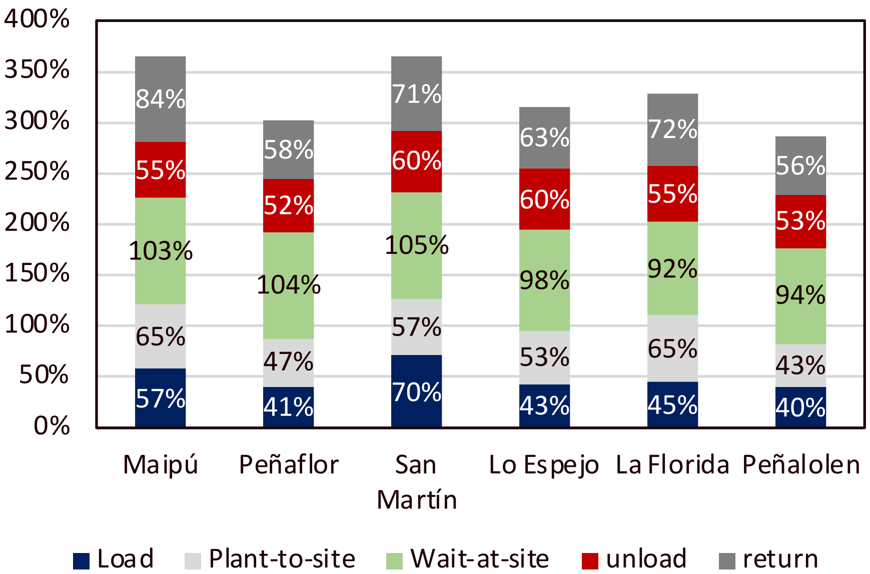
Geographic distribution of sites during 2017

Characterization of Process Stages

Processing times per office branch



Coefficient of variation of process times



Outline

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Conceptualization of final model

Parameters? Constraints?, Objectives? Response?

Requests:
- Site.
- Time.
- SKU.
- Volume.
- Client type
- Unloading time
- Spacing.
- Train.

} Demand

Branch offices and plants:
- Location.
- Types of products
- Speed $\left(\frac{M3}{min}, SKU\right)$.
- Times of adjustment of product density
- Production costs SKU.

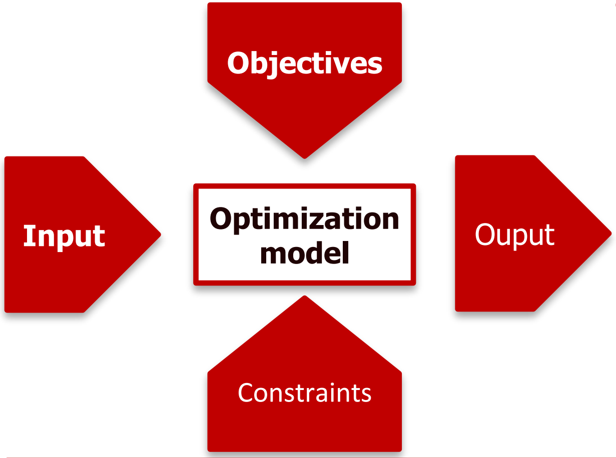
Fleet (N)
- Capacity.
- Type (own, contracted. spot)

} Resources

Transport network
- Travel times
- Travel costs

} Arcs

- Minimize production costs.
- Minimize fixed transportation costs (mixer).
- Minimize variable transportation costs.
- Minimize delays.



- Shifts of truck operators.
- Maximum delay per request.
- Discrete starting times of operators shifts.

Answers:
- In what plant to produce each specific dispatch
- At what time the dispatch has to be produced.

} Scheduling

- Which truck will perform each dispatch

} Dispatch

- Number of mixers required at each time

} Mixer Planning

Modelo entero mixto propuesto

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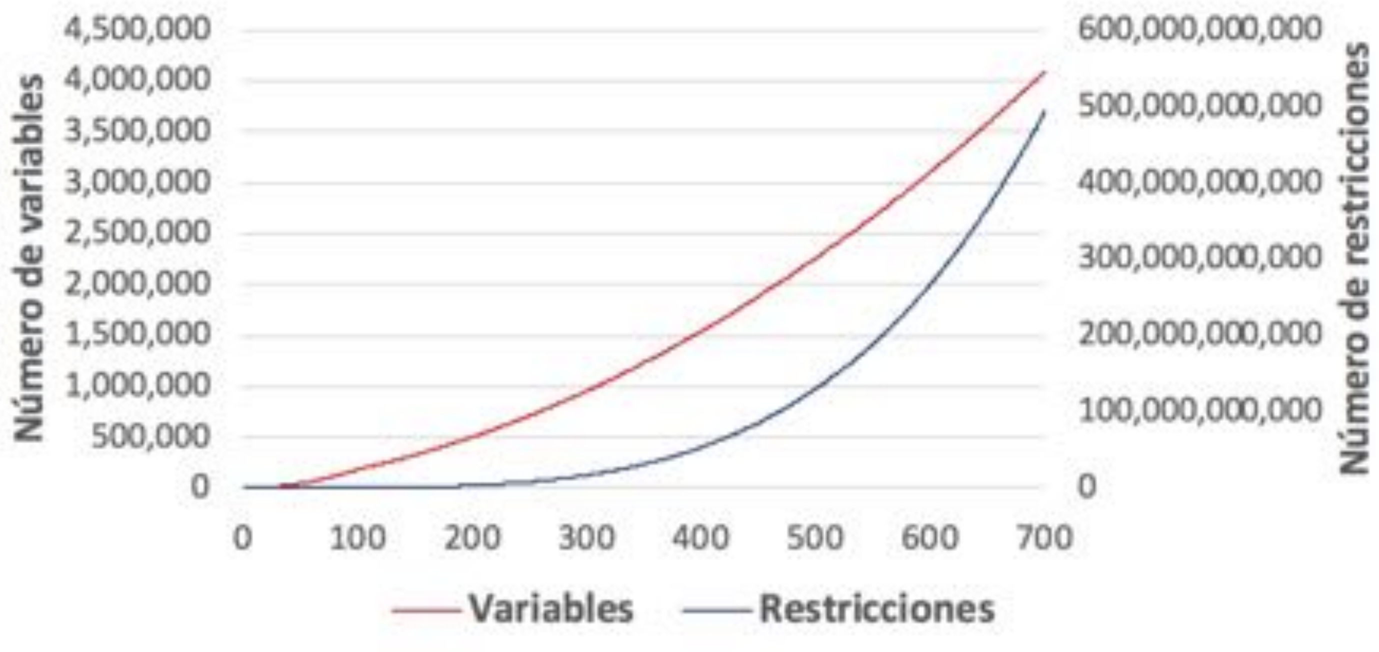
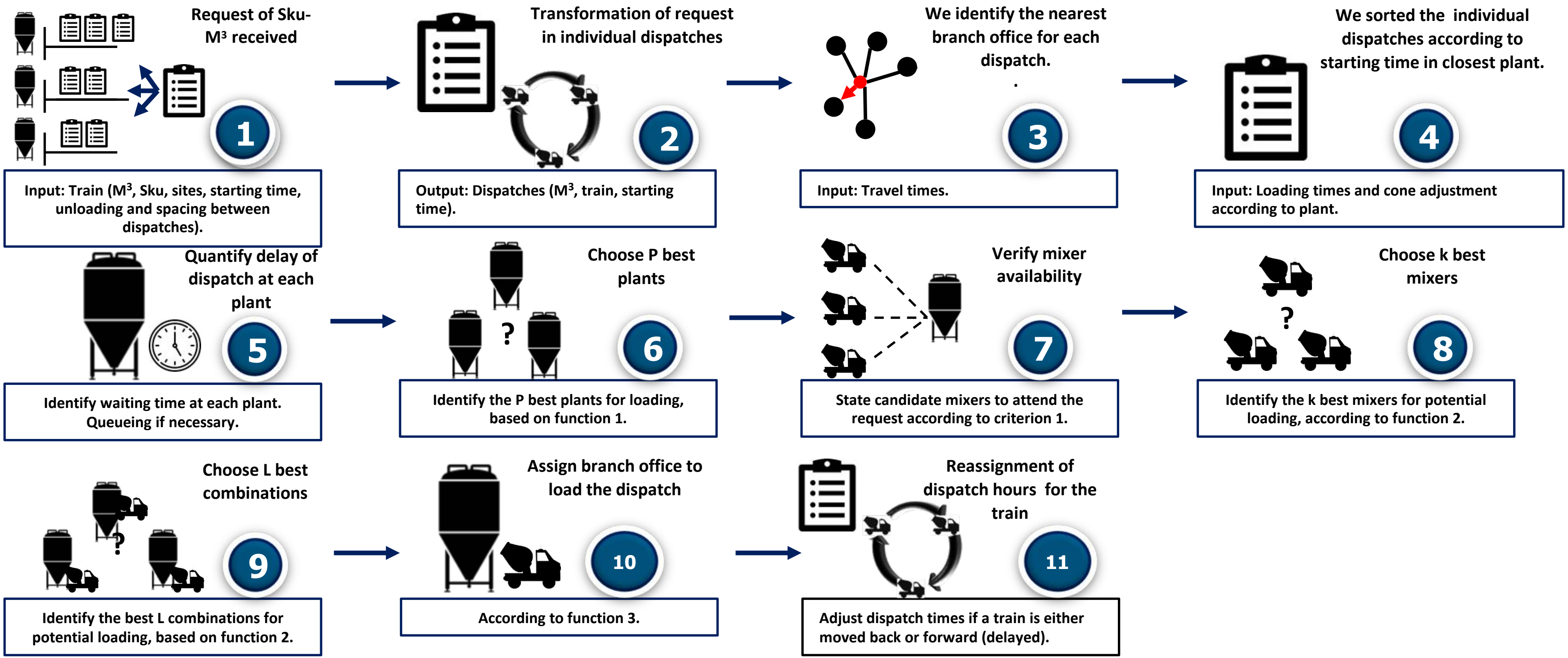
Variable	Tipo	Definición
y_i	No negativa	Tiempo de atraso sobre ventana horaria de despacho i, en minutos
t_i	No negativa	Hora de inicio de carga en depósito de despacho i, en minutos
x_{ivk}	Binaria	Igual a 1 si despacho i es realizado en vehículo v, en el k-ésimo *slot*; Igual a 0, en otro caso.
S_{idk}	Binaria	Igual a 1 si despacho i es realizado en depósito d, en el k-ésimo *slot*; Igual a 0, en otro caso.
μ_{idv}	Binaria	Igual a 1 si despacho i se carga en depósito d en vehículo v; Igual a 0, en otro caso.
λ_{idv}	Binaria	Igual a 1 si luego de despacho i se vuelve a depósito d en vehículo v; Igual a 0, en otro caso.

Modelo entero mixto propuesto



Cantidad de variables y restricciones según el número de despachos

Solution scheme: Fixed fleet dispatch allocation



Solution scheme: Fixed fleet dispatch allocation

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Functions

1: \$C. Production + \$C. Transport + \$ C. Delay (Step 6)
2: \$C. Production + \$C. Transport + \$ C. Delay + penalty on the number of deliveries already assigned (Steps 8-9)
3: GRASP using best plant-mixer combinations, according to function 2. (Step 10)

$$P(Branch_i) = \frac{Cost_i^{-1}}{\sum_j Cost_j^{-1}}$$

Criteria

1:The truck must be able to:

- Going back from last site assigned to dispatch branch office, travel to current site and go back to the original branch office, before the end of his labour day.
- Starting his labour day not later than 60 minutes after the ideal starting time in plant.

Objective function

\$C. Production + \$C. Transport + \$ C. Delay

Pseudocodes

Initialization

ADH Algorithm

Object

$Dispatches = \emptyset,\ Trains = \emptyset,\ Depots = \emptyset,\ Branch\ offices = \emptyset,\ Orderlist = \emptyset, Mixers = \emptyset$

Calculated Load Start

For $i \in Dispatch$

  $Dispatches_i.LoadStart = Dispatches.hour - time\{Depots_j \rightarrow Depots.location\}(Dispatches_i.Depots\}$

  $Dispatches_i.LoadStart -= (Coneadjust + Depots.m3formin \cdot Dispatches.m3)$

Computing loading times at closest plants for each dispatch, and sort dispatches according to loading time at closest plant

ADH Algorithm

Dispatches Order

For $i \in Dispatch$

  $J = 0$

  While $Dispatches_{Orderlist_{i-j}}.LoadStart > Dispatches_i.LoadStart$

    $J++$

    $Orderlist_{i-j}.insert = i$

Pseudocodes

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Computing production and transportation costs, and selecting tuple

ADH Algorithm

Depots and Mixers Allocations
For $i \in Dispatch$
    For $j \in Dispatches_i.Depots$
        $C = Depots_{Dispatches_i.depot}.idle * DelayCost + ProductionCost_j$
        For $k \in Mixers$
            $C += Cost_{Mixers_k.dispatch-Dispatches_i.depotDispatches_i.depots_j} + Cost_{Dispatches_i.depot-i} + Cost_{i-Mixers_k.depots_j} - Cost_{Mixers_k.dispatch-Mixers_k.depots_j}$
            $Tuple(i,j,k) = C$
            Select depots random with probability function inverse: $Tuple(i,j,k)$

Propagation of delays to respect minimum headway allowed between consecutive elements of trains

ADH Algorithm

Propagation
    For $j \in Dispatches_i \rightarrow train.dispatches$
        If $Dispatches_{j-1}.hour < Dispatches_j.hour + \min\_spacing$
        $Dispatches_j.hour += \min\_spacing$
    Function Dispatches Order run

Pseudocodes

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Computing Total Costs

ADH Algorithm

$\textbf{Total Cost}$

$For\ i \in Dispatch$

 $CT_1 += Dispatches_i.ProdCost$

 $CT_1 += Dispatches_i.delay \cdot Dispatches_i.Costformindelay$

 $CT_1 += Dispatches_i.mixerscost_{Dispatches_i.mix}$

$CT_2 = CT_1$

$For\ i \in Mixers$

 $CT_2 += Mixers_i.cost$

Outline

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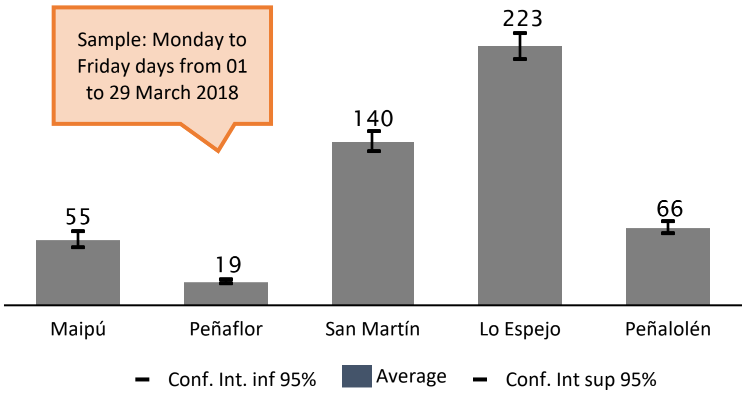
To test the algorithm, we work with data from March 2018, with a sample of 21 days from Monday to Friday

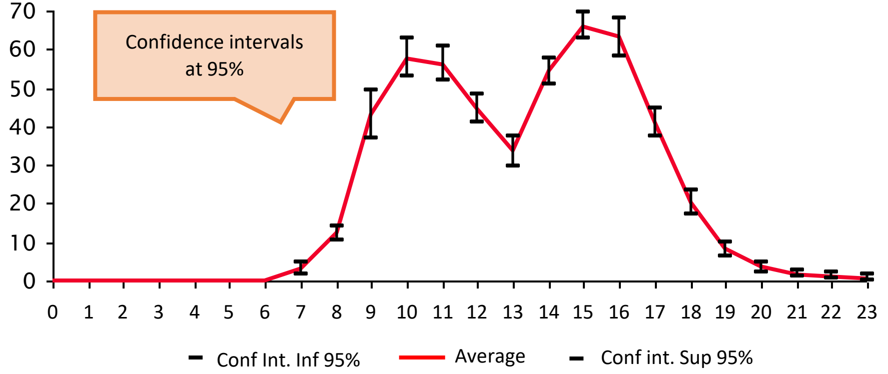
Test instances

	Dispatchs/day	Trains/day	Available mixers
Average	**511**	**203**	**171**
Min	401	160	165
Max	621	240	178

Tests are performed over a diverse sample under operational conditions considering real shifts of mixers

Demand pattern of dispatchs March 2018(1)



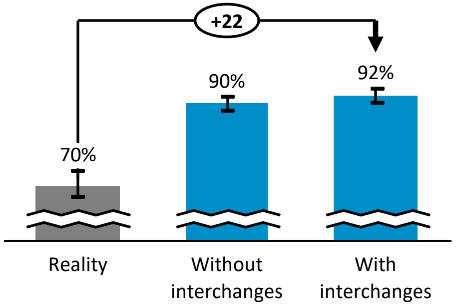


(1) Built according to the real schedule of plants and trucks to requests for Monday to Friday days in March 2018

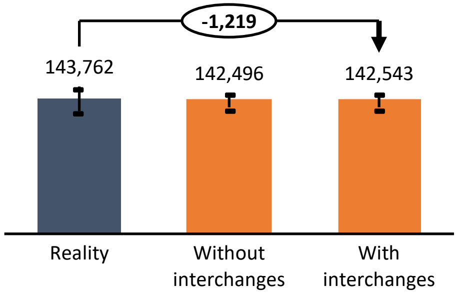
The use of Optimization module implies a potential improvement in puntuality without increasing operational costs

Main indicators(1)

Punctuality Std15 (%)

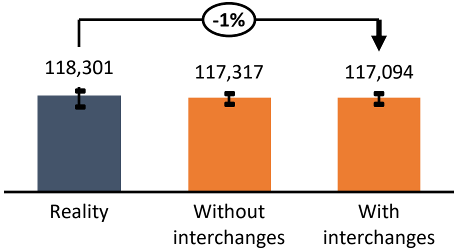


Operational Costs (1000 CLP/day)

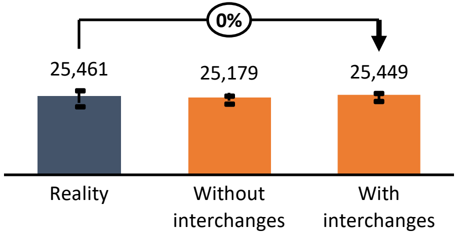


Potential improvement of ~22% in punctuality Std 15 without increasing costs of production and transport

Production Cost (1000 CLP/día)



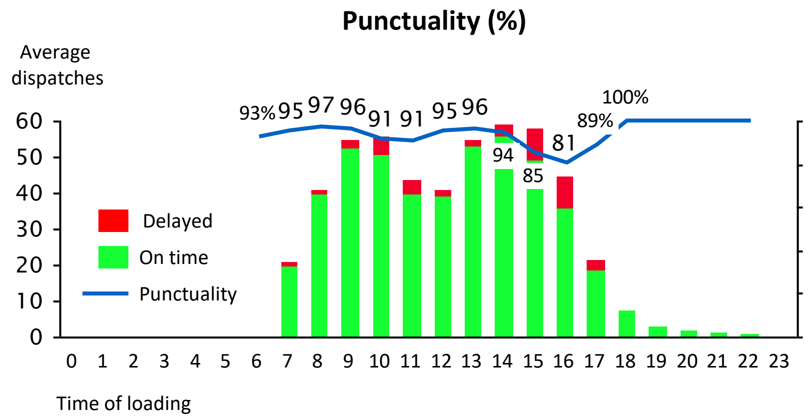
Transport cost (1000 CLP/día)

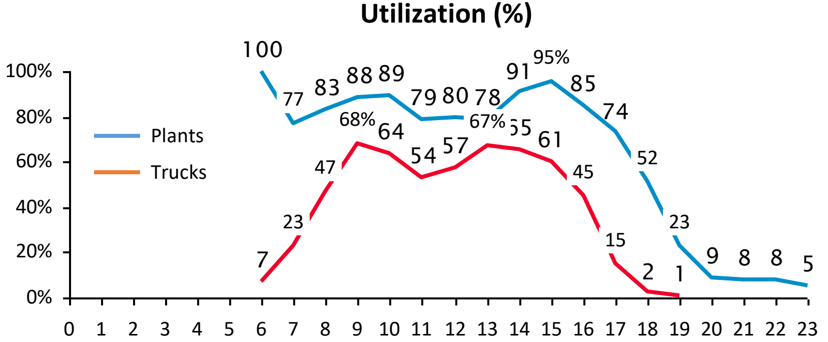


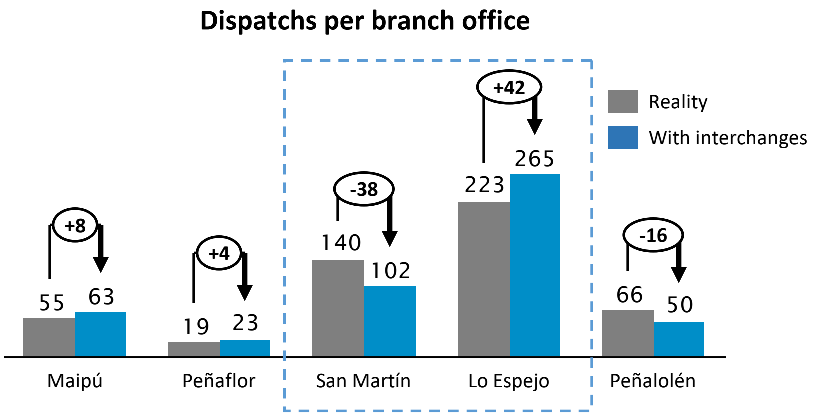
(1) Built according to the real schedule of plants and trucks to requests for Monday to Friday days in March 2018

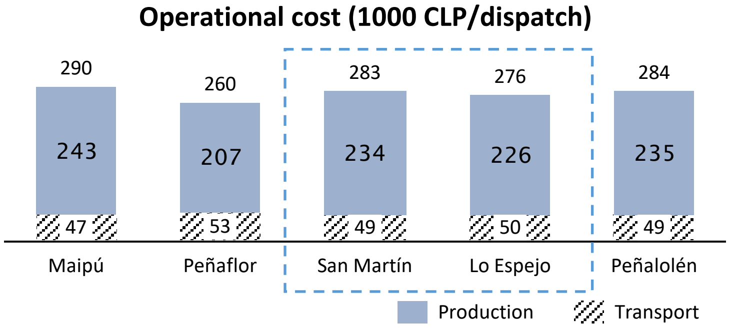
The algorithm performs properly, identifying potential improvements by tuning the parameters to fulfill the necessities of the company

Punctuality vs utilization per hour (1)







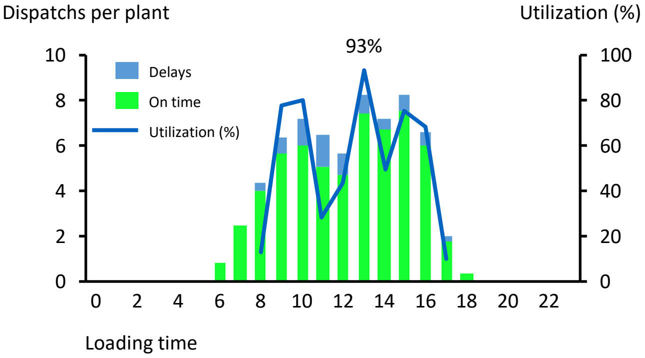


(1) Built based on results for 21 labour days during March 2018 under without interchanges scenario

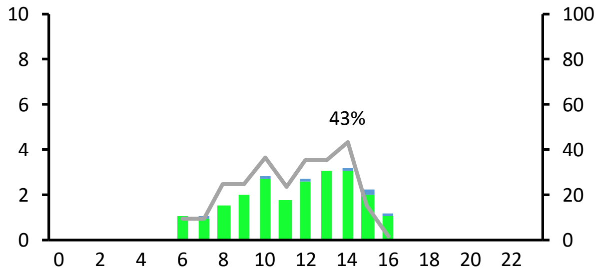
Overloading at Lo Espejo branch office generates a loss in punctuality in order to optimize costs

Punctuality and utilization per hour and branch office: Delay cost $1000 CLP/min

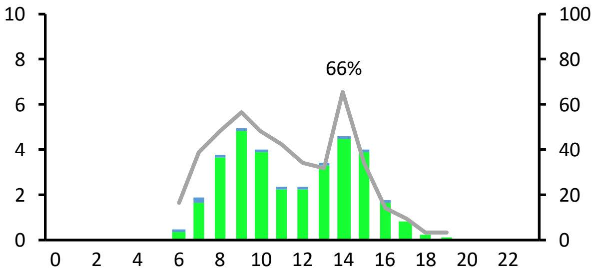
Maipú



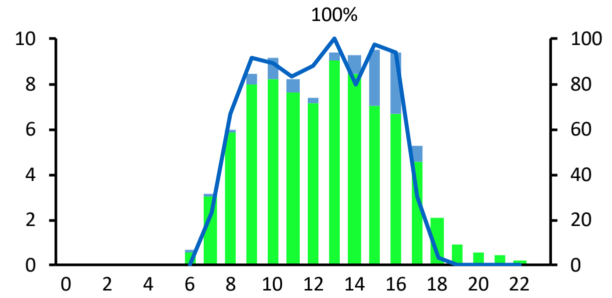
Peñaflor



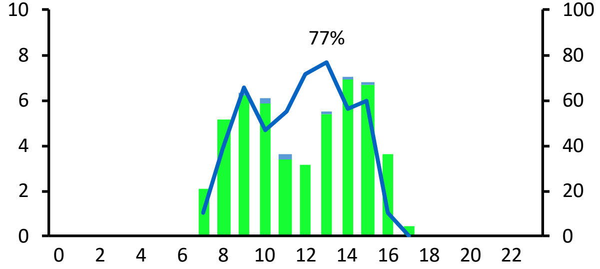
San Martín



Lo Espejo



Peñalolén

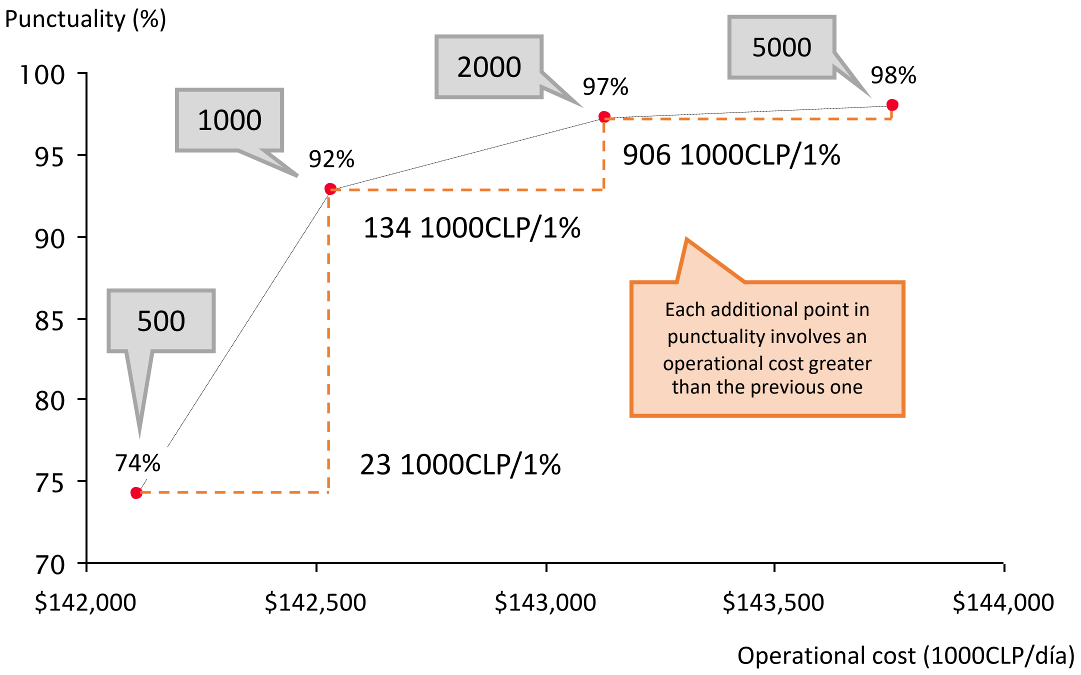


It is possible to adjust the delay cost parameter to further improve punctuality

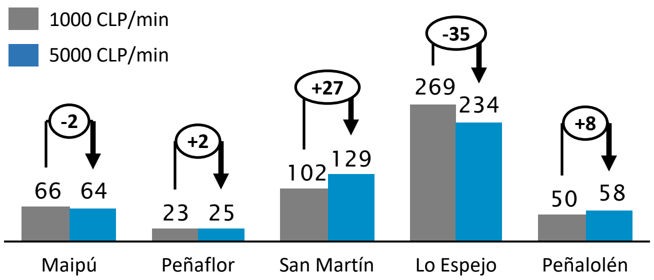
It is important to define the delay cost weight depending on the final objective of the company

Delay cost tests

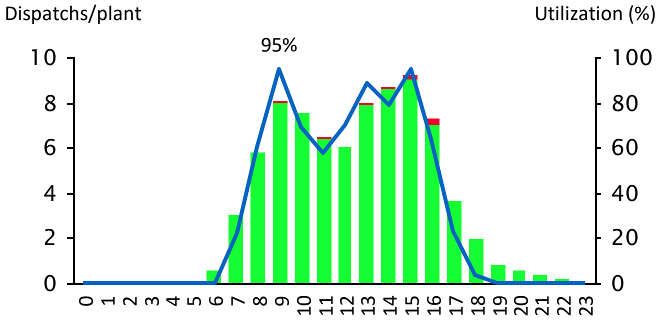
Punctuality and operational cost for different delay cost weights (CLP/min)



Dispatchs per plant for different delay cost weights

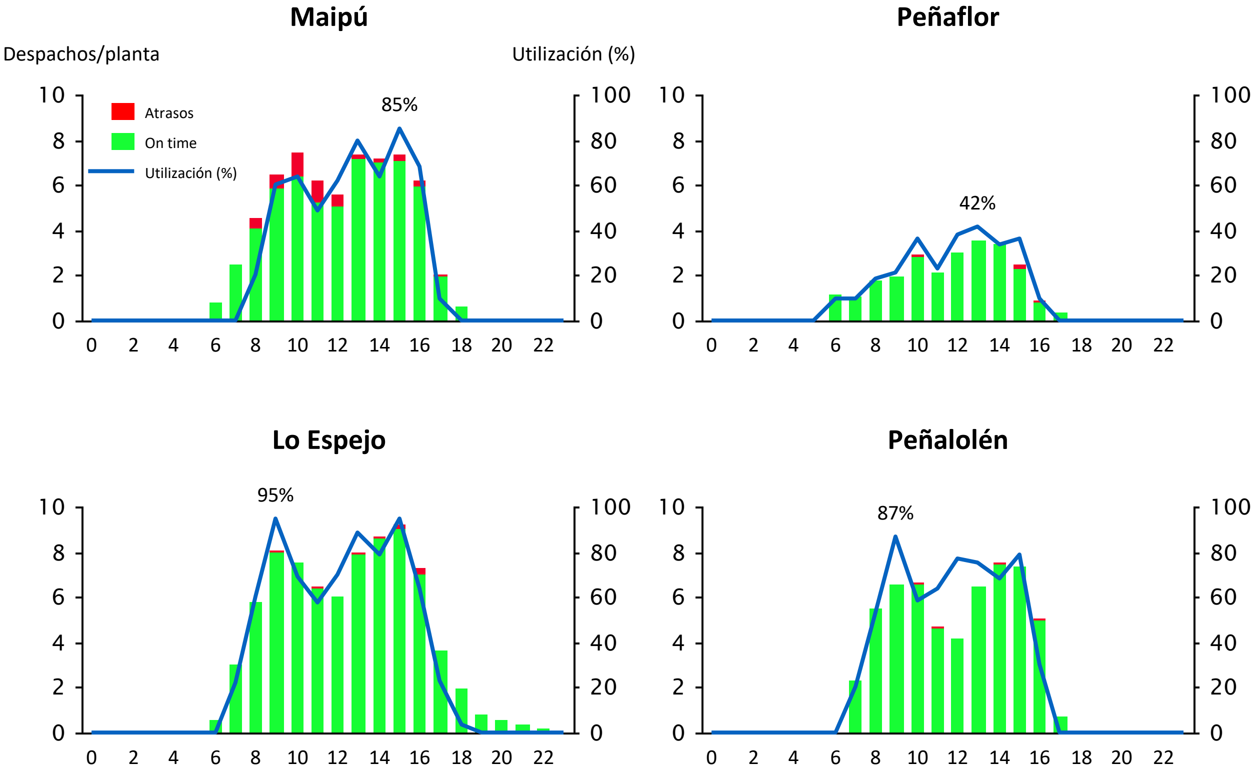


Punctuality and utilization per hour in Lo Espejo



Es importante definir el costo de atraso en función del valor real que la puntualidad aporta a la compañía

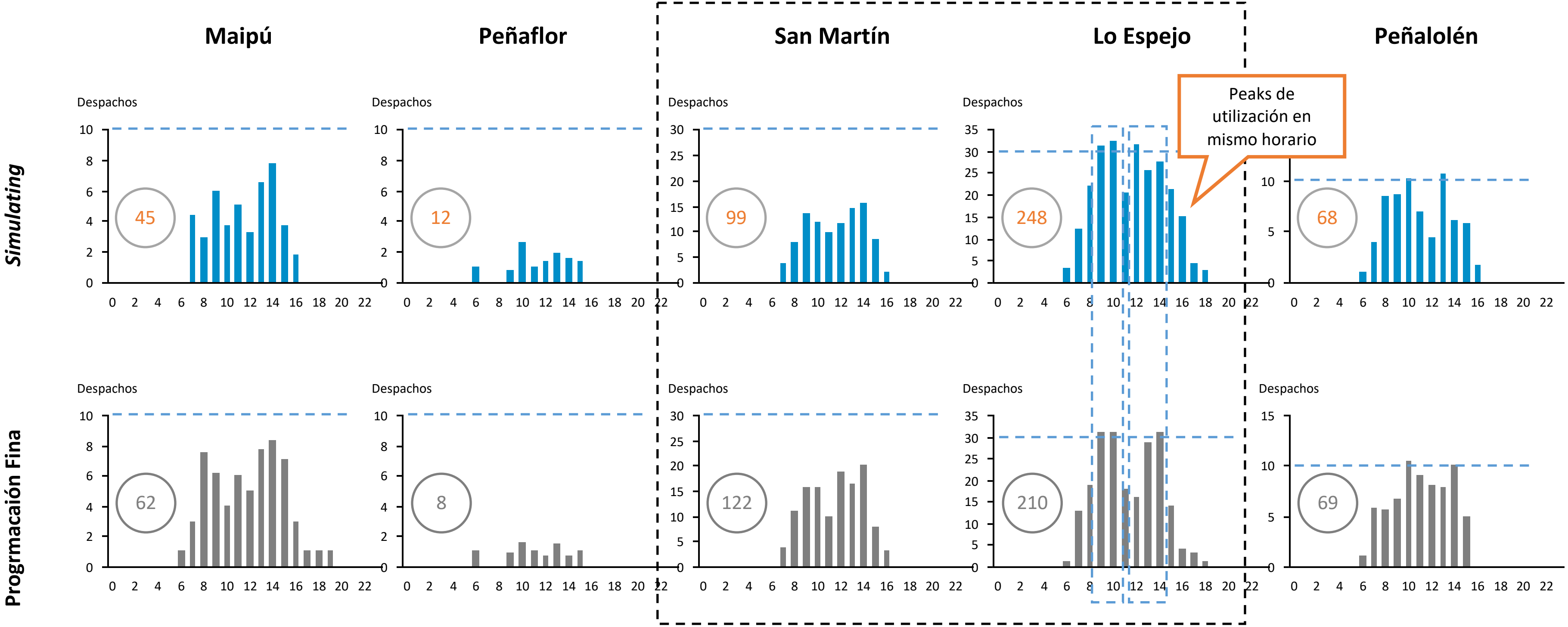
Puntualidad y utilización por hora y sucursal: Costo Atraso $5000 CLP/min



Costo operacional (M CLP/día)	$143.762
Puntualidad (%)	97,9%

Como resultado se obtiene un balance de cargas por sucursal con mayor utilización de Lo Espejo en horarios valle

Distribución de cargas por sucursal (1)



- - Límite teórico de capacidad por hora de la sucursal

(xx) Número total de despachos asignados a una sucursal

(1) Construidos según los resultados entregados por Optimix el 28/06/2018 a las 22:00, simulando el día 29/06/2018 con 9% de cancelación

Además de evaluar los costos operacionales y puntualidad, también nos interesa que la asignación a mixers sea justa

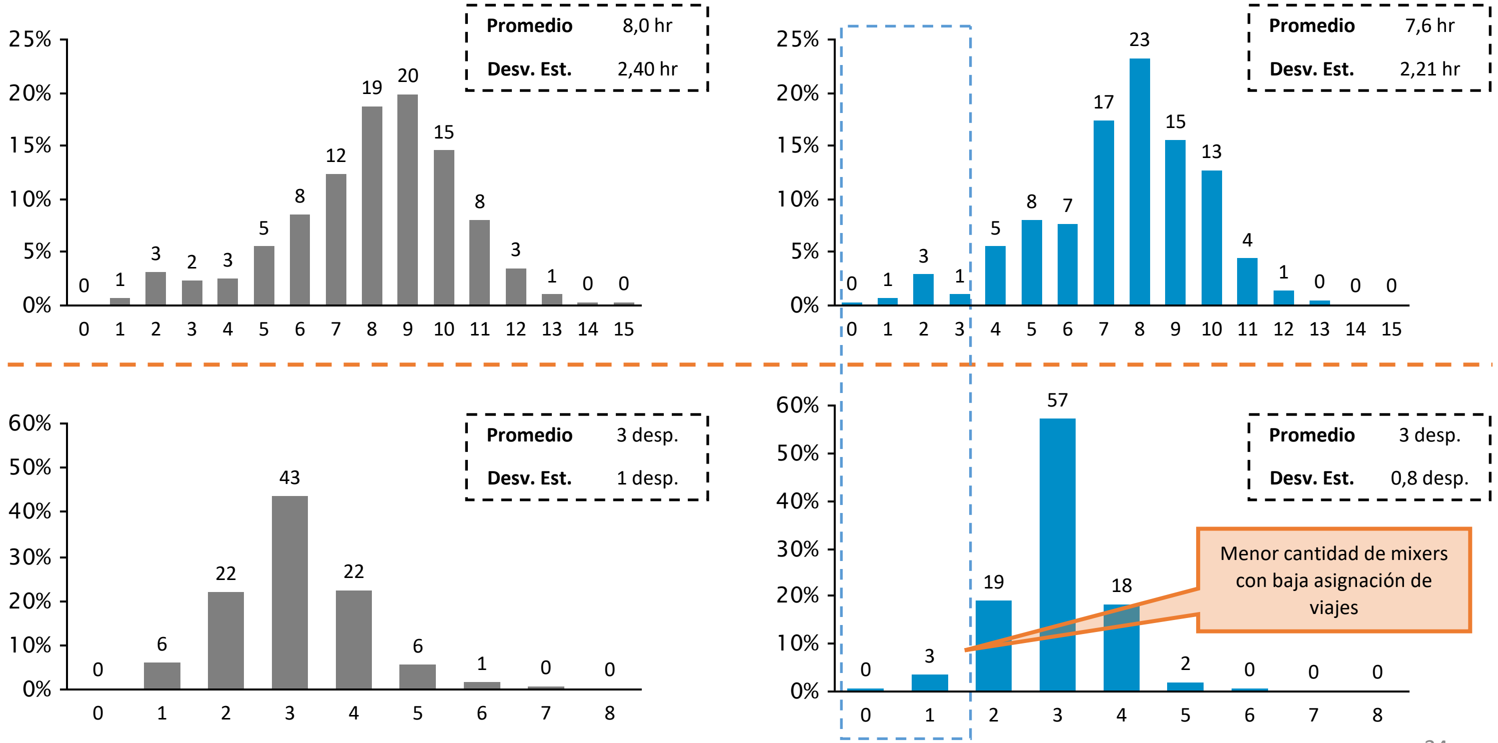
Comparación de jornadas y despachos por camión

Asignación real[1]

Asignación *Simulating* con Intercambio

Largo jornada

Cantidad de despachos

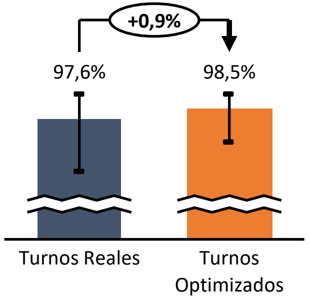


(1) Construidos según la asignación real de plantas y camiones a pedidos para los días lunes a viernes de marzo 2018

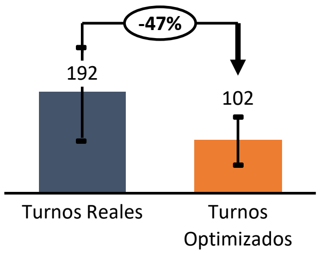
El algoritmo de optimización de turnos mejora los niveles de servicio principalmente los días de alta demanda

Principales Indicadores (1)

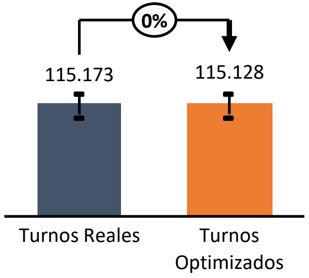
Puntualidad Std15 (%)



Atrasos (min/día)

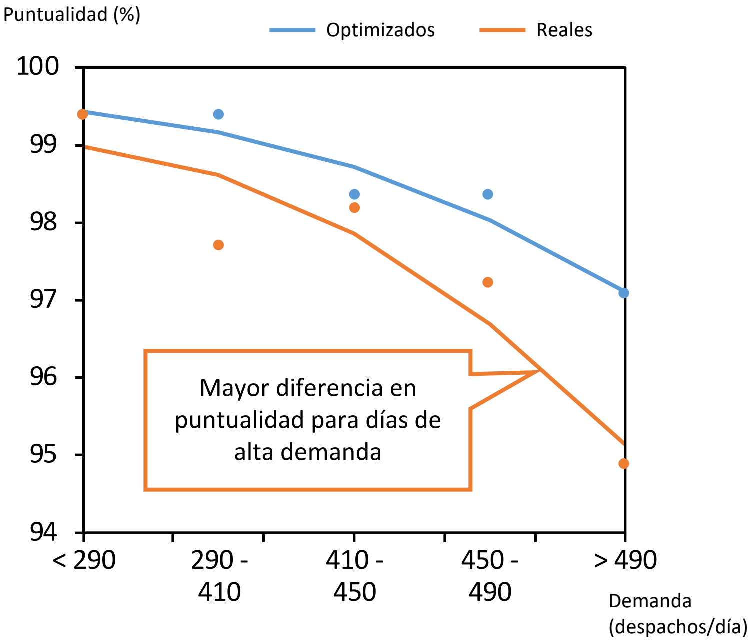


Costo Operacional (M CLP/día)



Puntualidad aumenta en 1 punto porcentual en promedio **sin impacto en costo operacional ni modificar el número de mixers por sucursal**

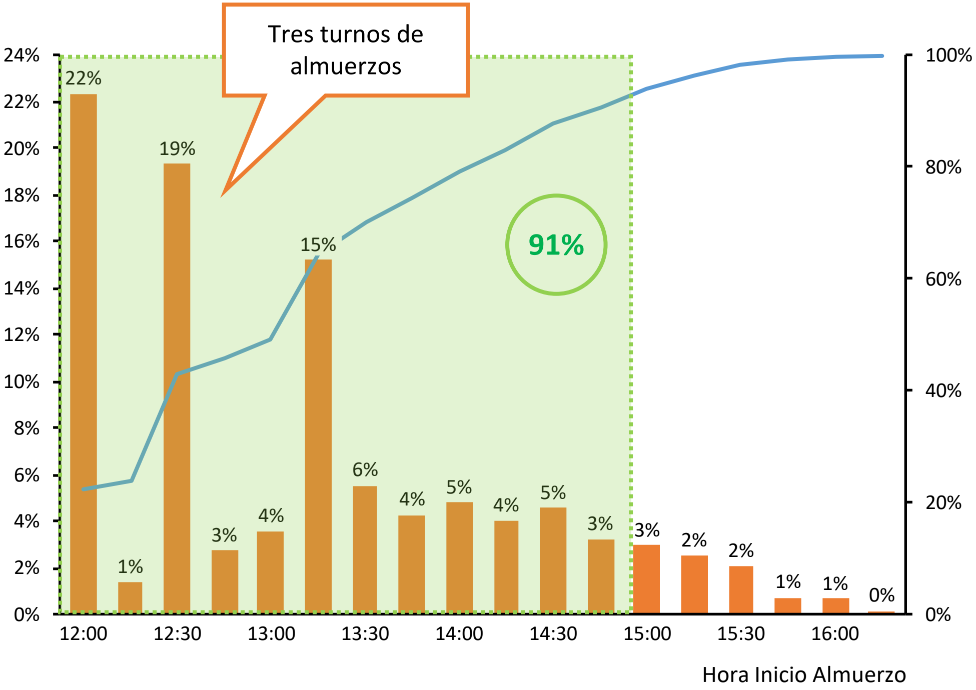
Puntualidad v/s demanda diaria

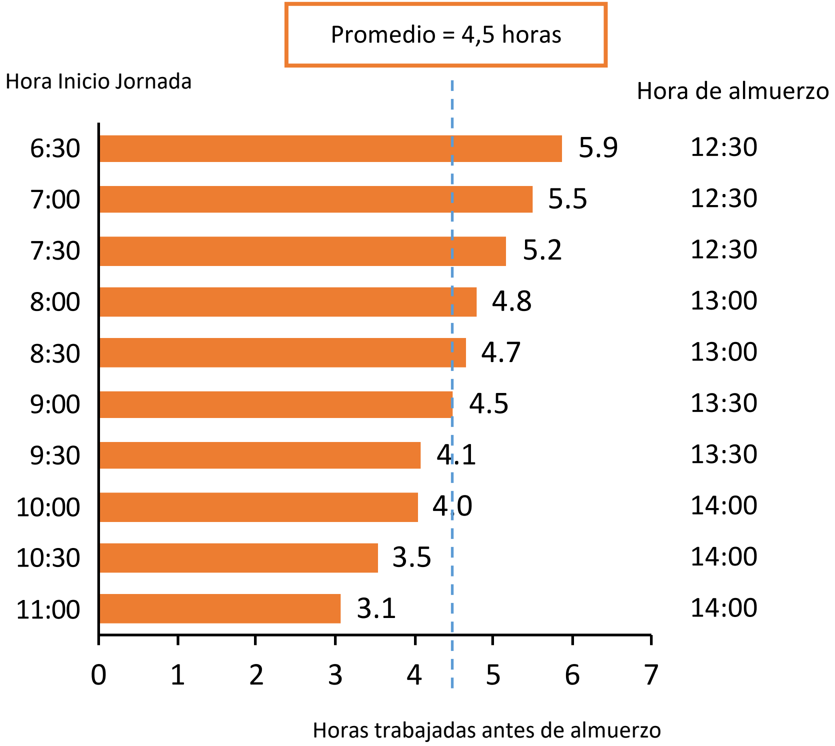


(1) Construidos según la asignación real de plantas y camiones a pedidos para 25 días hábiles de junio, julio y agosto 2018

Según la lógica actual, el 91% de los conductores iniciaría su horario de almuerzo antes de las 15:00 horas

Distribución de los turnos de almuerzo [1]





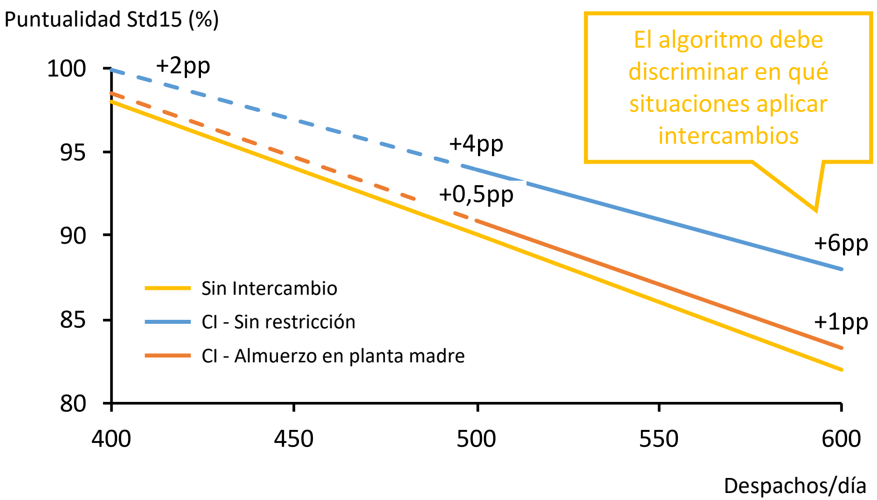
Lógica: los conductores pueden almuerzan en 3 turnos, a partir de las 12:00, 12:40 y 13:20

(1) Construidos según la asignación real de plantas y camiones a pedidos para 25 días hábiles de junio, julio y agosto 2018

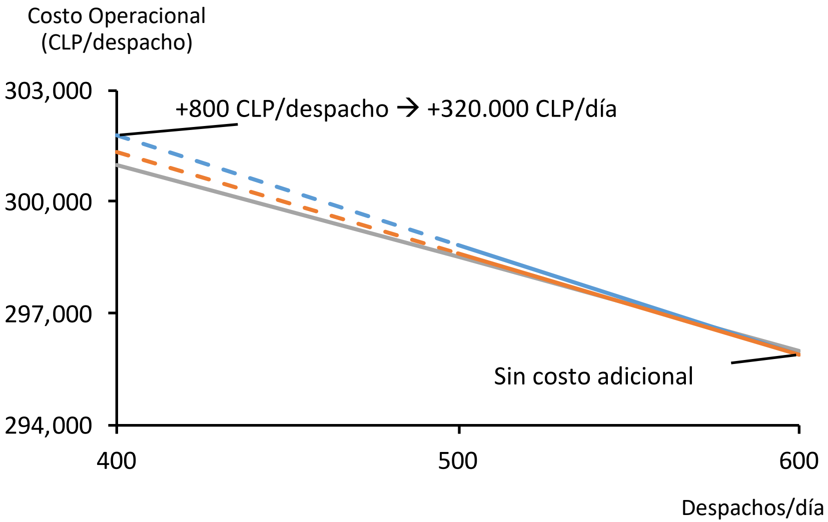
Los intercambios toman relevancia en escenarios de mayor demanda

Estudio del impacto de intercambiar de mixers

Diferencia de Puntualidad v/s Número de Despachos



Diferencia de Costo Operacional v/s Número de Despachos



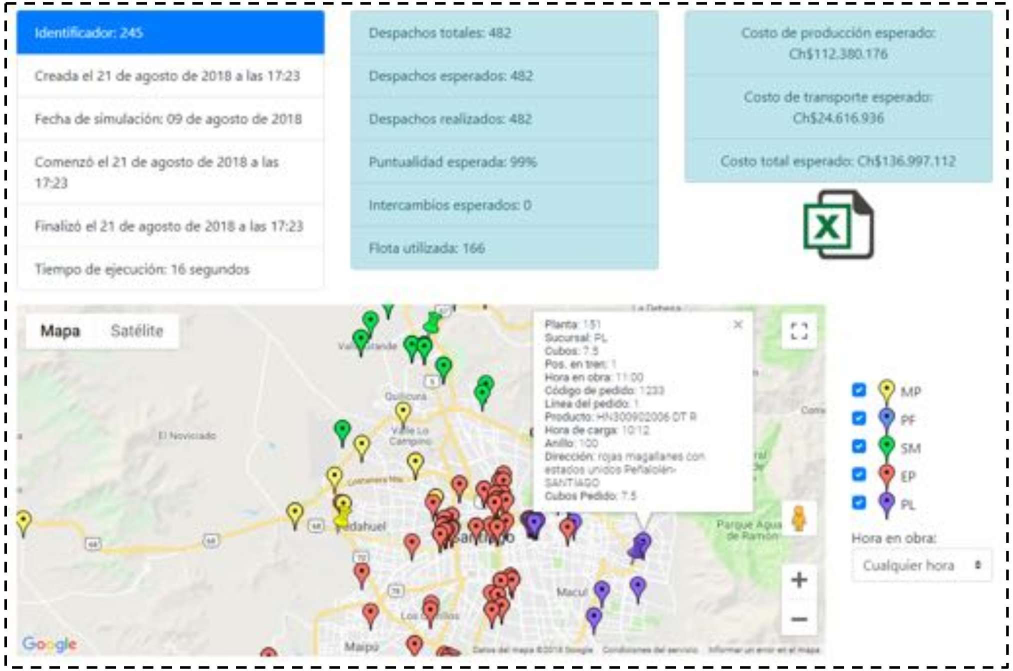
Los intercambios deberían ser implementados sólo en días en que resulte conveniente

(1) Estimado según valores de octubre 2018 y normalizado según demanda del último año móvil

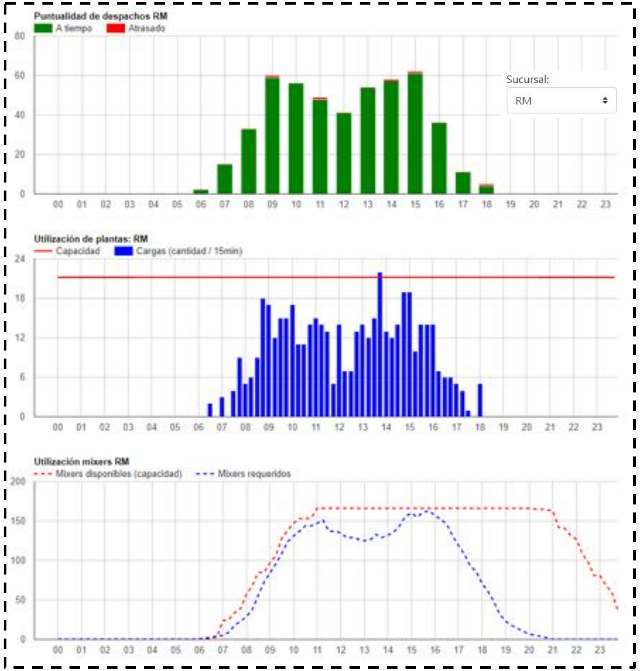
Con módulo de Optimización, PF contará con información de puntualidad y costo esperados, distribución geográfica y utilización de recursos

Proceso de uso de *Simulating*

Indicadores generales y mapa de pedidos



Gráficos de puntualidad y utilización



Con la optimización, se puede identificar fácilmente las consecuencias de la interacción de los recursos críticos **y** con esto **facilitar su oportuna gestión**

Con módulo de Optimización, Operaciones recibirá un reporte con la necesidad de mixers cada 15 min de operación

Reporte de necesidad de mixers por hora

Hora Requerida	Sucursal	Requeridos	Holgura
6:00:00	EP	0	0
6:15:00	EP	0	0
6:30:00	EP	2	0
6:45:00	EP	0	0
7:00:00	EP	3	0
7:15:00	EP	1	0
7:30:00	EP	3	0
7:45:00	EP	3	0
8:00:00	EP	2	0
8:15:00	EP	4	1
8:30:00	EP	4	0
8:45:00	EP	4	0
9:00:00	EP	4	0
9:15:00	EP	7	1
9:30:00	EP	4	0
9:45:00	EP	2	0
10:00:00	EP	3	0
10:15:00	EP	5	0
10:30:00	EP	4	0
10:45:00	EP	3	0
11:00:00	EP	4	0
11:15:00	EP	6	0
11:30:00	EP	2	0
11:45:00	EP	0	0
12:00:00	EP	0	0

Hora Requerida	Sucursal	Requeridos	Holgura
6:00:00	SM	0	0
6:15:00	SM	0	0
6:30:00	SM	0	0
6:45:00	SM	0	0
7:00:00	SM	1	0
7:15:00	SM	0	0
7:30:00	SM	0	0
7:45:00	SM	0	0
8:00:00	SM	1	1
8:15:00	SM	2	0
8:30:00	SM	2	1
8:45:00	SM	2	0
9:00:00	SM	3	2
9:15:00	SM	1	0
9:30:00	SM	2	1
9:45:00	SM	2	0
10:00:00	SM	3	2
10:15:00	SM	2	0
10:30:00	SM	2	1
10:45:00	SM	2	0
11:00:00	SM	3	1
11:15:00	SM	2	0
11:30:00	SM	2	0
11:45:00	SM	1	0
12:00:00	SM	0	0

Esta información deberá ser validada por el equipo de Operaciones y cargada al sistema de citación

Outline

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1. Motivation and problem description
2. Literature review
3. Data analysis
4. Development of solution algorithm
5. Results
6. **Conclusions and ongoing research**

Conclusions and ongoing research

- We present and approach for solving a practical ready mix concrete dispatch problem.
- This is a complex practical problem. Attempts to formulate a MIP and solve it with a commercial solver were not successful.
- We implemented a GRASP heuristic which can be adapted for three temporal level of decisions.
- Experiments with historical data show substantial improvements in reducing delays and costs with respect to current company operation.
- Implementation of monthly, weekly, daily planning and dynamic rescheduling versions.
- Tuning a PSO algorithm to decide the best starting times of truck driver shifts.

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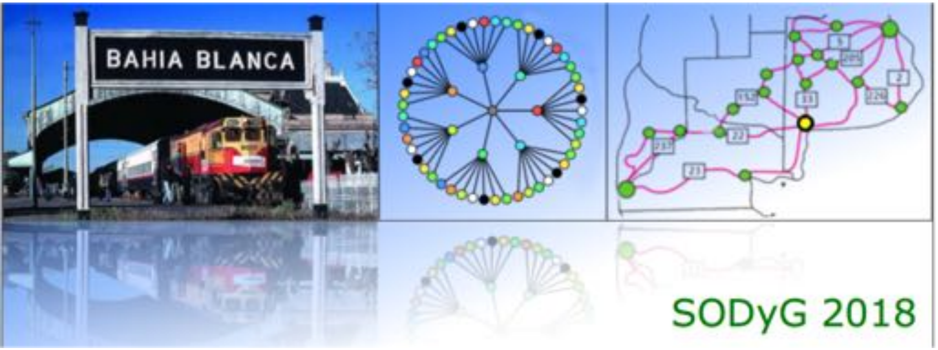
Conclusions and ongoing research

- Implementation of simulation platform:
  - Validation and testing the optimization methods.
  - Support the development of dynamic dispatch.

- Implementation of a decision support system based on the algorithms for practical use.
- Development of analytical models using a decomposition procedure to test the quality of the heuristic.



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Modelamiento y resolución de un problema real de producción y despacho de concreto en un área urbana

Cristián E. Cortés

Universidad de Chile