

EVALUATION OF DIFFERENT DELIVERY POLICIES IN THE CEMENT INDUSTRY

Juan Carlos Coloma López and Michel Groenner

Advisor: Dr. Chris Caplice

Massachusetts Institute of Technology. Cambridge, May 22nd 2018



AGENDA

Introduction

Literature
review

Method

Results &
discussion

Conclusion



AGENDA

Introduction

Literature
review

Method

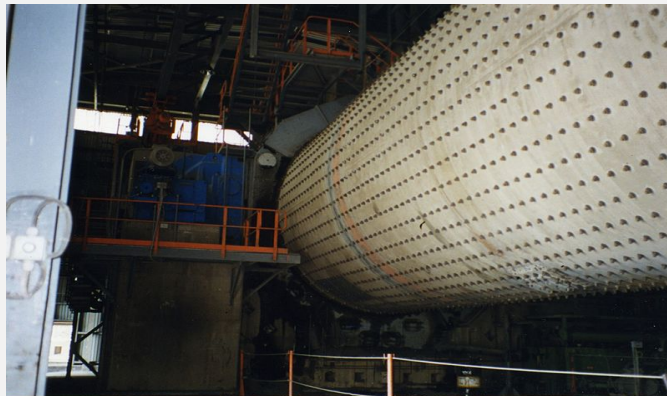
Results &
discussion

Conclusion



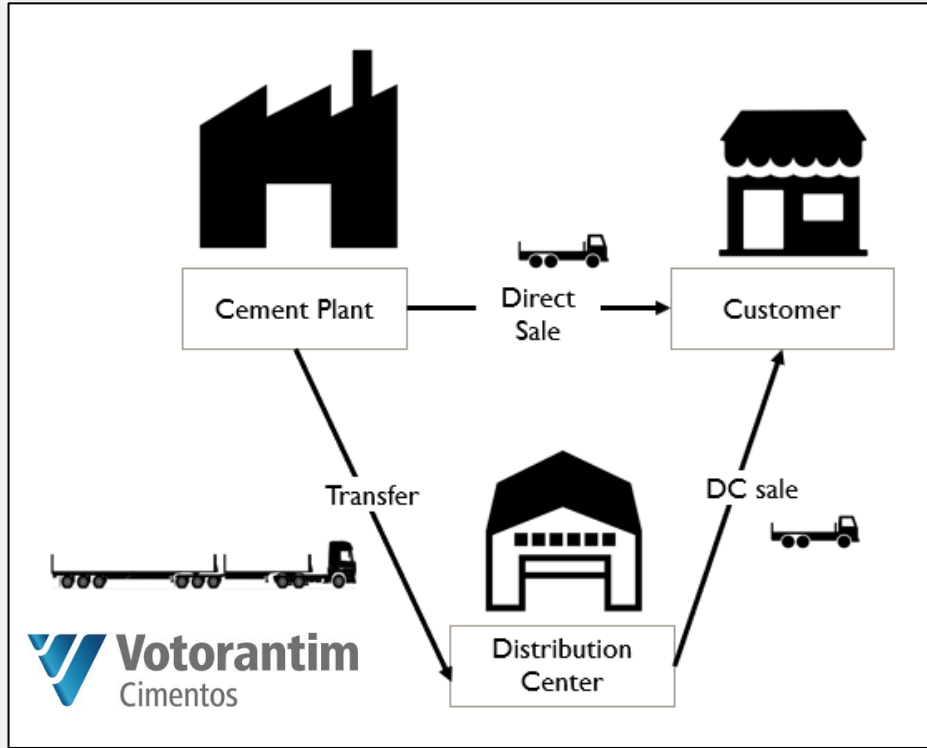
CEMENT INDUSTRY

- Mature and relevant industry (\$450 billion)
- Cement is present in all regions; Portland: most common type
- Two processes: 1) clinker fabrication 2) mixture with gypsum + additives
- Energy and materials intensive, but low cost per weight \$111/ton - \$5.5/bag
- Distribution: bulk / bags

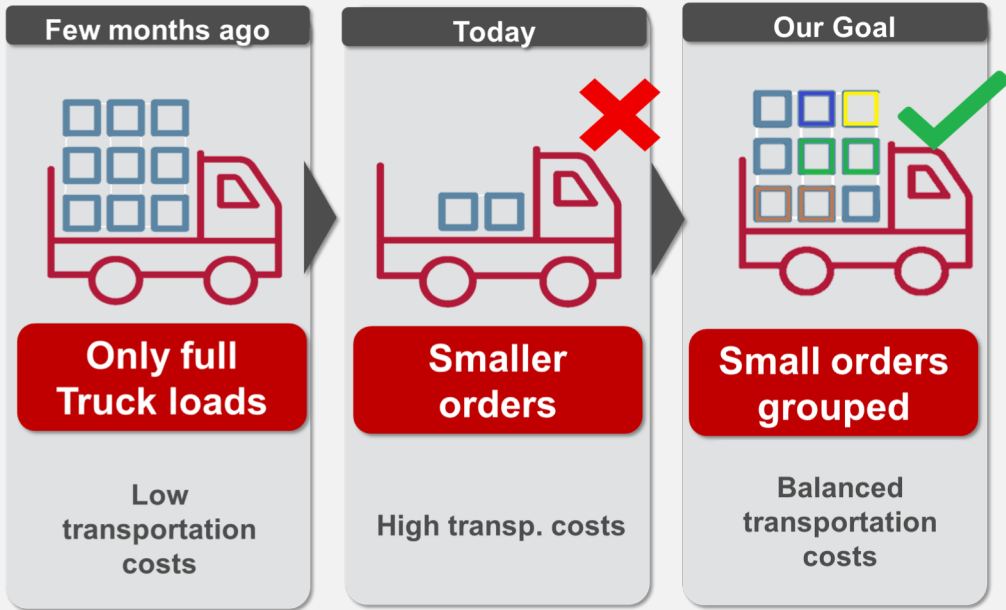


VOTORANTIM CIMENTOS

- Belongs to Votorantim Group: one of the largest industrial conglomerate in Iberoamerica
- #8 larger cement company worldwide #1 in Brazil (our geographic frame)
- Vertically integrated (quarries \leftrightarrow Distribution centers)
- Project focused on transportation to customers from DC, done by independent drivers



PROBLEM & POSSIBLE SOLUTION



AS IS (Every day deliveries)

Mon	Tue	Wed	Thu	Fri

Region A1- Cost: 4 truck trips - Client impact: 0



Delivery Policy:

Region	Mon	Tue	Wed	Thu	Fri
A1		X		X	

TO BE (Deliveries according to a policy)

Mon	Tue	Wed	Thu	Fri

Region A1 - Cost: 2 truck trips - Client impact: 8 pallets

AGENDA

Introduction

**Literature
review**

Method

Results &
discussion

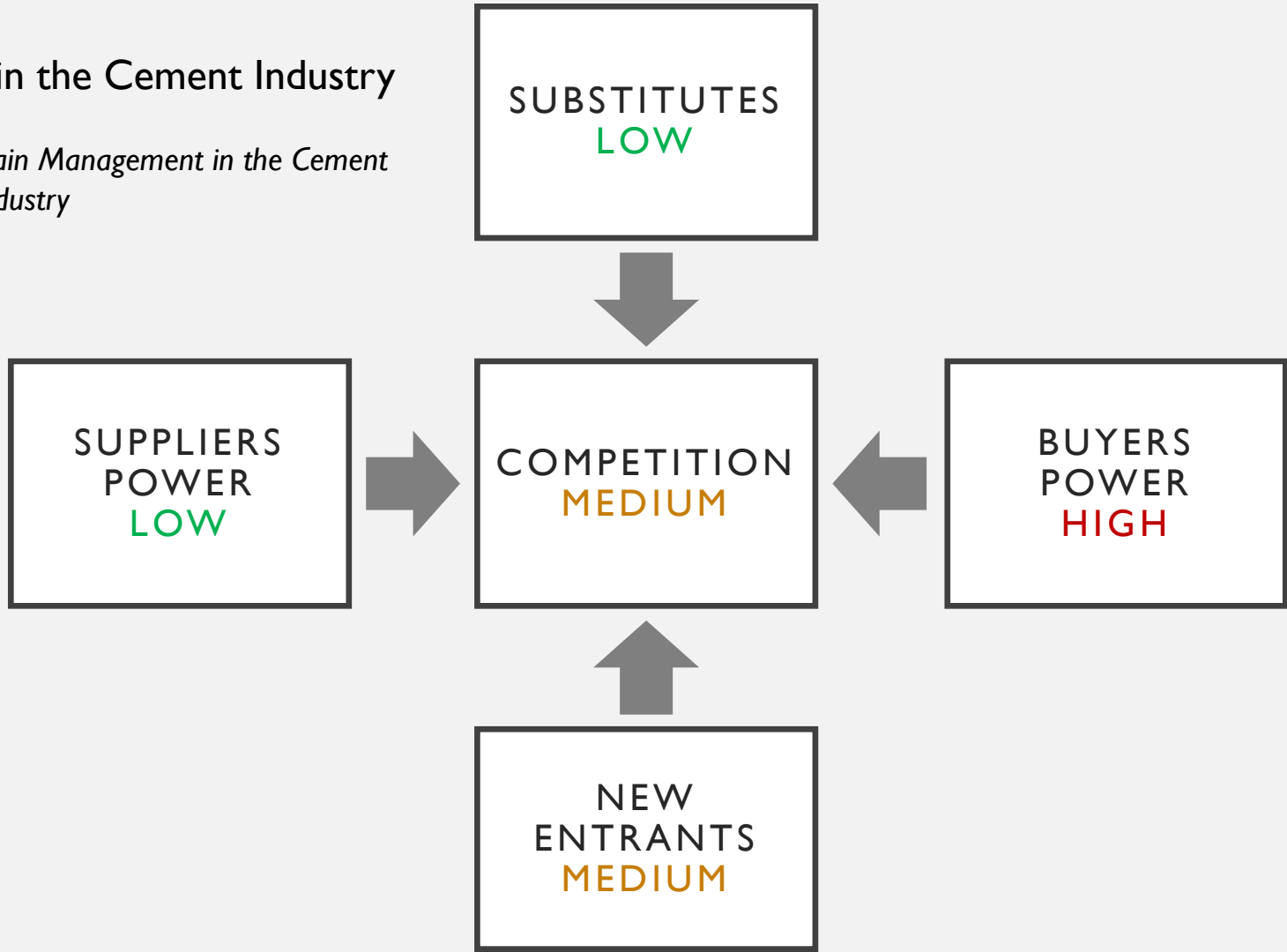
Conclusion



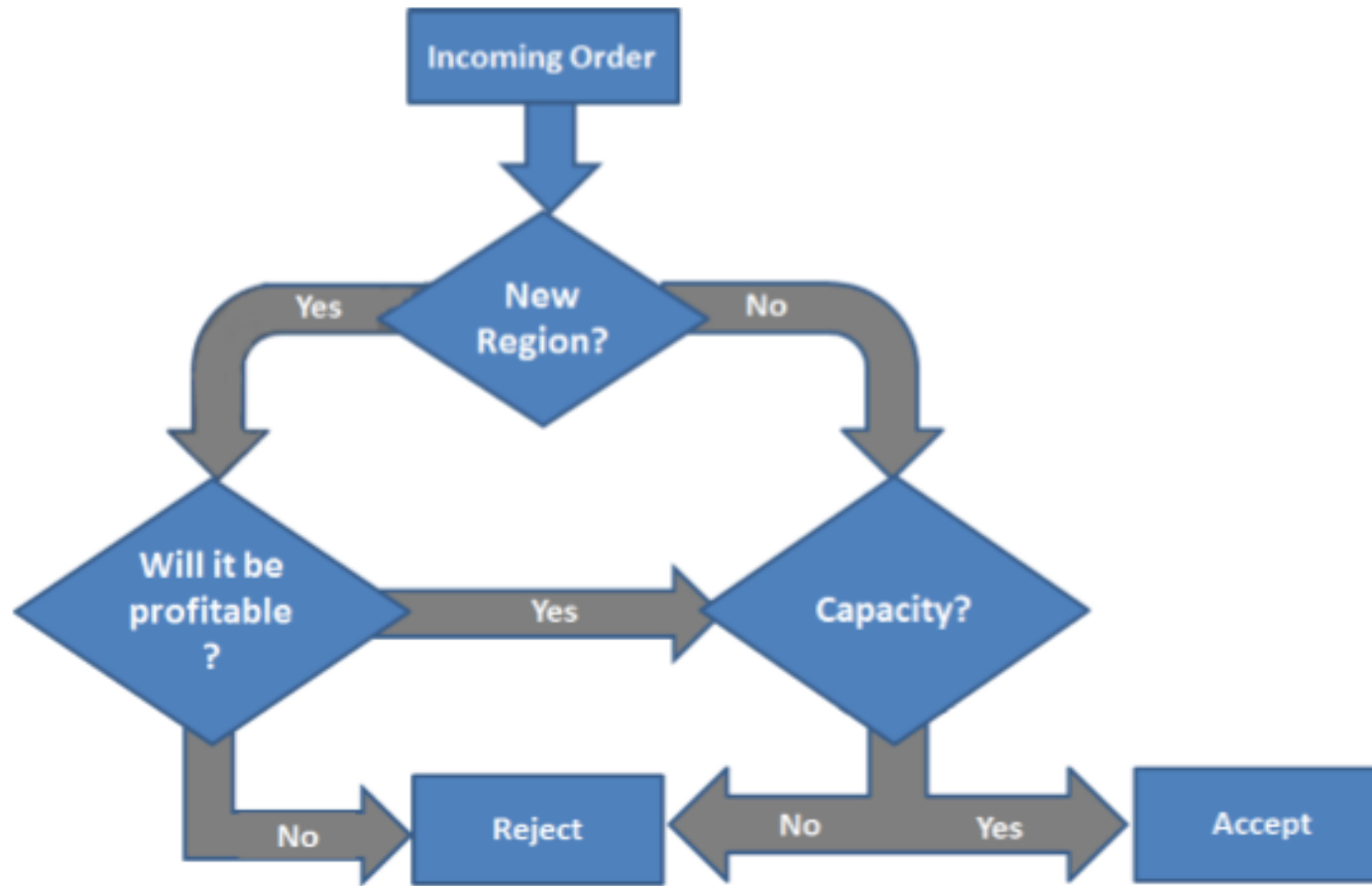
STRATEGIC VIEW

Porter's Five Forces in the Cement Industry

Agudelo (2009) *Supply Chain Management in the Cement Industry*



INSIGHT FROM RETAIL



Nisar and Rosenzweig (2014) *Real-Time Order Acceptance in Transportation Under Uncertainty*



AGENDA

Introduction

Literature
review

Method

Results &
discussion

Conclusion



METHOD

Algorithm goal

- (i) Assign final delivery date (FD_i)
- (ii) Calculate penalty cost
- (iii) Calculate transportation cost

Type of data, for each ORDER i

R_i	=	<i>region for delivery</i>
N_i	=	<i>number of pallets</i>
OD_i	=	<i>ordered date</i>
RD_i	=	<i>requested (by the customer) delivery date</i>
FD_i	=	<i>final delivery date</i>

Transportation Cost:

$$T = \sum_{k=1}^l \sum_{j=1}^m t_j * \text{roundup} \left[\sum_{i=1}^n \frac{N_{ijk}}{G}, 0 \right]$$

Sub-indices:

i : set of orders, $i \in \{1, \dots, n\}$; j : set of the regions, $j \in \{1, \dots, m\}$; k : set of days, $k \in \{1, \dots, l\}$;

Cost parameters:

t_j : charge rate of a truck from the DC to region j . Unit: R\$ / truck.

T : total transportation cost. Unit: R\$.

CED: penalty cost of early delivery per pallet per day. Unit: R\$ / pallet / day.

CLD: penalty cost of late delivery per pallet per day. Unit: R\$ / pallet / day.

G : truck capacity = 7 pallets/truck.

Decision variables:

A : Allowed Delivery Dates. $\in A$.

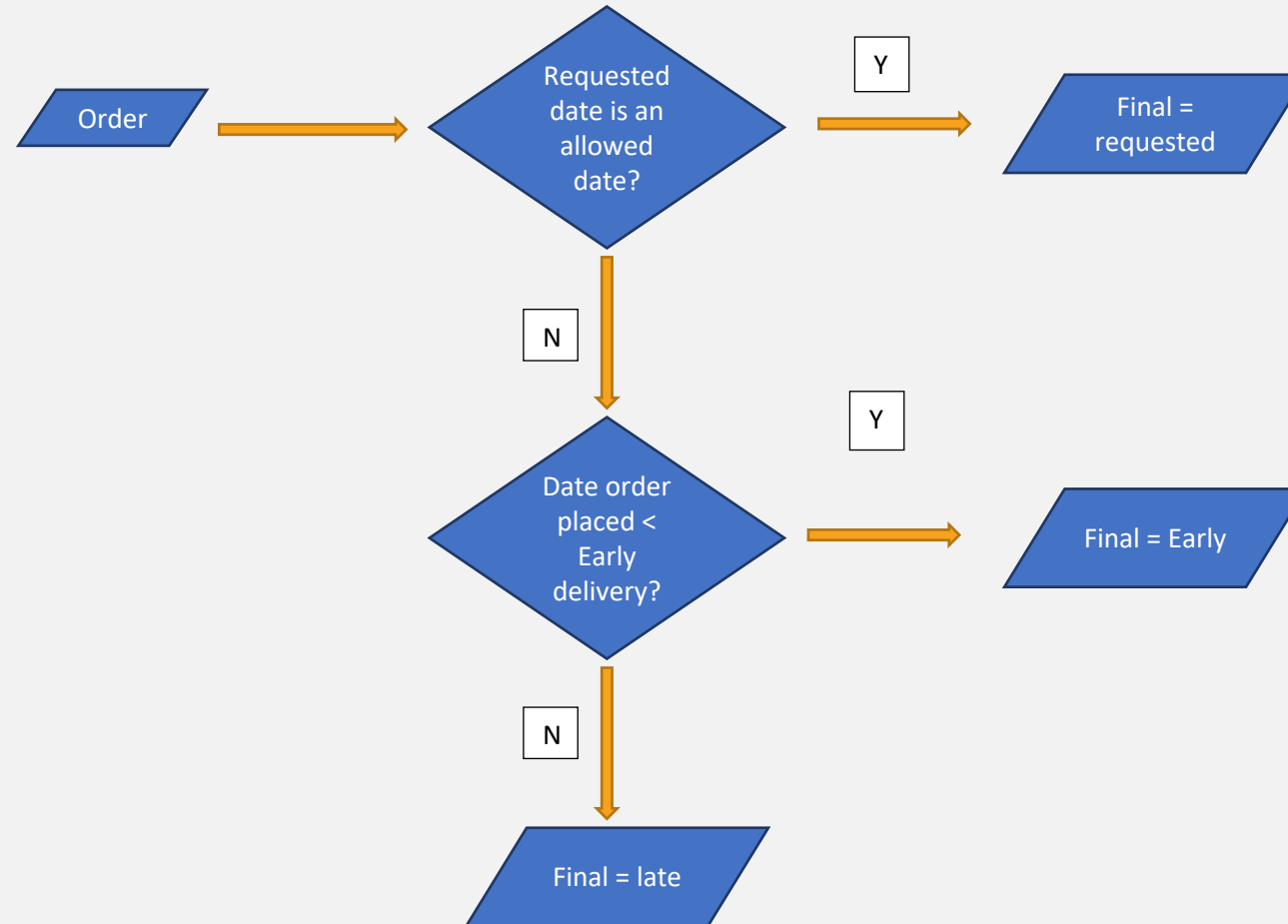
$ED f(A, RD_i)$ is the day $\in A$ prior to RD_i . That is, the earlier date it can be delivered.

$LD f(A, RD_i)$ is the day $\in A$ after to RD_i . That is, the later day it can be delivered.

Extra Transportation Cost:

$$T = \sum_{k=1}^l \sum_{j=1}^m t_j * \left[\sum_{i=1}^n \frac{N_{ijk}}{G} \right]$$

NAÏVE ALGORITHM



NAÏVE ALGORITHM

$A = \{T, R\}$

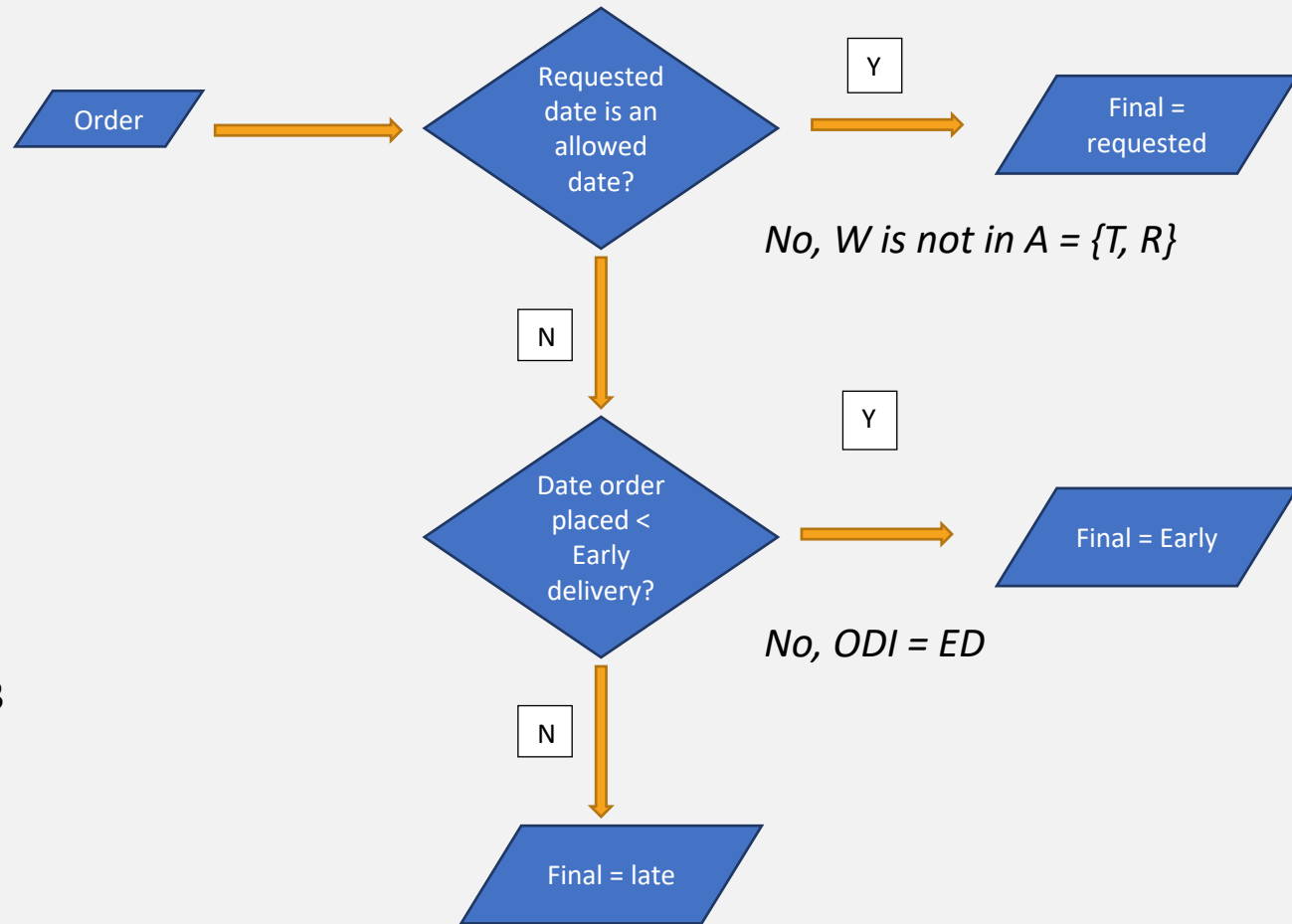
N (number of pallets) = 3 pallets

OD (ordered date when the was placed) = T

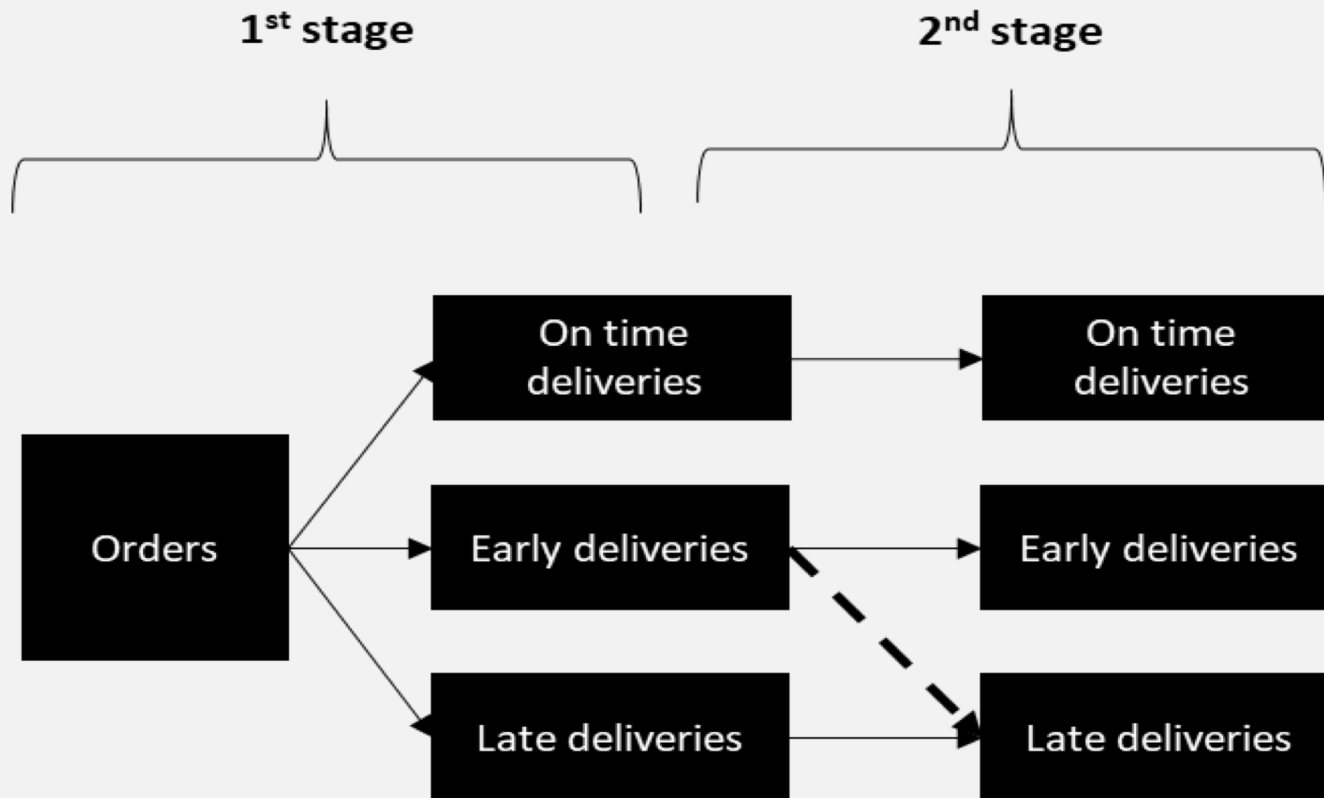
RD (customer requested delivery date) = W

FD (final delivery date) = to be determined.

In this case $FD = R$ and penalty costs = $CLD * 3$ pallets.



THRESHOLD ALGORITHM



$$\sum_{i=1}^n N_{ijk} < \beta, FD_i = LD$$

AGENDA

Introduction

Literature
review

Method

**Results &
discussion**

Conclusion



NAÏVE RESULTS

Region	Everyday / 1 - 1 - 1 - 1 - 1			M - W - F / 1 - 0 - 1 - 0 - 1			Delta	
	Extra transp. Cost	Penalty Costs	Relevant costs	Extra transp. Cost	Penalty Costs	Relevant costs	Extra transp. Cost	Relevant costs
Region 1	R\$ 30.504	R\$ -	R\$ 30.504	R\$ 24.835	R\$ 6.378	R\$ 31.213	-23%	2%
Region 2	R\$ 21.428	R\$ -	R\$ 21.428	R\$ 16.598	R\$ 10.050	R\$ 26.648	-29%	20%
Region 3	R\$ 34.484	R\$ -	R\$ 34.484	R\$ 29.132	R\$ 1.062	R\$ 30.194	-18%	-14%
Region 4	R\$ 10.547	R\$ -	R\$ 10.547	R\$ 10.362	R\$ 7.704	R\$ 18.066	-2%	42%
Region 5	R\$ 21.336	R\$ -	R\$ 21.336	R\$ 15.445	R\$ 3.186	R\$ 18.631	-38%	-15%
Region 6	R\$ 21.544	R\$ -	R\$ 21.544	R\$ 19.534	R\$ 258	R\$ 19.792	-10%	-9%
Region 7	R\$ 20.011	R\$ -	R\$ 20.011	R\$ 17.079	R\$ 366	R\$ 17.445	-17%	-15%
Region 8	R\$ 21.401	R\$ -	R\$ 21.401	R\$ 19.896	R\$ 228	R\$ 20.124	-8%	-6%
Region 9	R\$ 17.752	R\$ -	R\$ 17.752	R\$ 13.496	R\$ 8.586	R\$ 22.082	-32%	20%
Region 10	R\$ 32.487	R\$ -	R\$ 32.487	R\$ 22.968	R\$ 7.488	R\$ 30.456	-41%	-7%
Region 11	R\$ 25.493	R\$ -	R\$ 25.493	R\$ 16.142	R\$ 9.378	R\$ 25.520	-58%	0%
Region 12	R\$ 19.623	R\$ -	R\$ 19.623	R\$ 13.190	R\$ 20.208	R\$ 33.398	-49%	41%
Region 13	R\$ 11.757	R\$ -	R\$ 11.757	R\$ 15.611	R\$ 4.956	R\$ 20.567	25%	43%
Region 14	R\$ 34.332	R\$ -	R\$ 34.332	R\$ 27.477	R\$ 4.062	R\$ 31.539	-25%	-9%
Region 15	R\$ 3.399	R\$ -	R\$ 3.399	R\$ 3.399	R\$ 180	R\$ 3.579	0%	5%
Region 16	R\$ 2.021	R\$ -	R\$ 2.021	R\$ 2.021	R\$ 18	R\$ 2.039	0%	1%
Region 17	R\$ 8.813	R\$ -	R\$ 8.813	R\$ 14.571	R\$ 6.894	R\$ 21.465	40%	59%
Region 18	R\$ 10.906	R\$ -	R\$ 10.906	R\$ 10.293	R\$ 534	R\$ 10.827	-6%	-1%
Region 19	R\$ 18.089	R\$ -	R\$ 18.089	R\$ 18.089	R\$ 6	R\$ 18.095	0%	0%
Region 20	R\$ 16.053	R\$ -	R\$ 16.053	R\$ 17.788	R\$ 2.016	R\$ 19.804	10%	19%
Region 21	R\$ 863	R\$ -	R\$ 863	R\$ 863	R\$ 30	R\$ 893	0%	3%
Region 22	R\$ 20.558	R\$ -	R\$ 20.558	R\$ 17.059	R\$ 120	R\$ 17.179	-21%	-20%
Total	R\$ 403.404	R\$ -	R\$ 403.404	R\$ 345.849	R\$ 93.708	R\$ 439.557	-17%	8%

In this case that constraining deliveries does not lead to a better solution.



NAÏVE RESULTS

Region	Everyday / 1 - 1 - 1 - 1 - 1			T - Th / 0 - 1 - 0 - 1 - 0			Delta	
	Extra transp. Cost	Penalty Costs	Relevant costs	Extra transp. Cost	Penalty Costs	Relevant costs	Extra transp. Cost	Relevant costs
Region 1	R\$ 30.504	R\$ -	R\$ 30.504	R\$ 16.899	R\$ 5.496	R\$ 22.395	-45%	-27%
Region 2	R\$ 21.428	R\$ -	R\$ 21.428	R\$ 10.750	R\$ 7.914	R\$ 18.664	-50%	-13%
Region 3	R\$ 34.484	R\$ -	R\$ 34.484	R\$ 25.385	R\$ 4.374	R\$ 29.759	-26%	-14%
Region 4	R\$ 10.547	R\$ -	R\$ 10.547	R\$ 7.587	R\$ 2.910	R\$ 10.497	-28%	0%
Region 5	R\$ 21.336	R\$ -	R\$ 21.336	R\$ 13.383	R\$ 798	R\$ 14.181	-37%	-34%
Region 6	R\$ 21.544	R\$ -	R\$ 21.544	R\$ 17.925	R\$ 14.292	R\$ 32.217	-17%	50%
Region 7	R\$ 20.011	R\$ -	R\$ 20.011	R\$ 14.799	R\$ 14.856	R\$ 29.655	-26%	48%
Region 8	R\$ 21.401	R\$ -	R\$ 21.401	R\$ 16.132	R\$ 6.834	R\$ 22.966	-25%	7%
Region 9	R\$ 17.752	R\$ -	R\$ 17.752	R\$ 8.177	R\$ 6.012	R\$ 14.189	-54%	-20%
Region 10	R\$ 32.487	R\$ -	R\$ 32.487	R\$ 16.621	R\$ 13.722	R\$ 30.343	-49%	-7%
Region 11	R\$ 25.493	R\$ -	R\$ 25.493	R\$ 11.466	R\$ 13.080	R\$ 24.546	-55%	-4%
Region 12	R\$ 19.623	R\$ -	R\$ 19.623	R\$ 8.649	R\$ 34.410	R\$ 43.059	-56%	119%
Region 13	R\$ 11.757	R\$ -	R\$ 11.757	R\$ 10.170	R\$ 198	R\$ 10.368	-13%	-12%
Region 14	R\$ 34.332	R\$ -	R\$ 34.332	R\$ 17.397	R\$ 6.708	R\$ 24.105	-49%	-30%
Region 15	R\$ 3.399	R\$ -	R\$ 3.399	R\$ 3.399	R\$ 312	R\$ 3.711	0%	9%
Region 16	R\$ 2.021	R\$ -	R\$ 2.021	R\$ 1.816	R\$ 144	R\$ 1.960	-10%	-3%
Region 17	R\$ 8.813	R\$ -	R\$ 8.813	R\$ 8.608	R\$ 72	R\$ 8.680	-2%	-2%
Region 18	R\$ 10.906	R\$ -	R\$ 10.906	R\$ 8.760	R\$ 612	R\$ 9.372	-20%	-14%
Region 19	R\$ 18.089	R\$ -	R\$ 18.089	R\$ 18.089	R\$ 1.218	R\$ 19.307	0%	7%
Region 20	R\$ 16.053	R\$ -	R\$ 16.053	R\$ 16.053	R\$ 12	R\$ 16.065	0%	0%
Region 21	R\$ 863	R\$ -	R\$ 863	R\$ 863	R\$ 282	R\$ 1.145	0%	33%
Region 22	R\$ 20.558	R\$ -	R\$ 20.558	R\$ 17.496	R\$ 1.122	R\$ 18.618	-15%	-9%
Total	R\$ 403.404	R\$ -	R\$ 403.404	R\$ 270.424	R\$ 135.378	R\$ 405.802	-33%	1%

Again, constraining deliveries does not lead to a better solution.



NAÏVE RESULTS

Region	Everyday / 1 - 1 - 1 - 1 - 1			Minimum Cost Policy				Delta	
	Extra transp. Cost	Penalty Costs	Relevant costs	Allowed days	Extra transp. Cost	Penalty Costs	Relevant costs	Extra transp. Cost	Relevant costs
Region 1	R\$ 30.504	R\$ -	R\$ 30.504	01010	R\$ 16.899	R\$ 5.496	R\$ 22.395	-81%	-36%
Region 2	R\$ 21.428	R\$ -	R\$ 21.428	01010	R\$ 10.750	R\$ 7.914	R\$ 18.664	-99%	-15%
Region 3	R\$ 34.484	R\$ -	R\$ 34.484	00100	R\$ 10.934	R\$ 7.932	R\$ 18.866	-215%	-83%
Region 4	R\$ 10.547	R\$ -	R\$ 10.547	01010	R\$ 7.587	R\$ 2.910	R\$ 10.497	-39%	0%
Region 5	R\$ 21.336	R\$ -	R\$ 21.336	00010	R\$ 6.313	R\$ 6.576	R\$ 12.889	-238%	-66%
Region 6	R\$ 21.544	R\$ -	R\$ 21.544	10100	R\$ 17.925	R\$ 402	R\$ 18.327	-20%	-18%
Region 7	R\$ 20.011	R\$ -	R\$ 20.011	10100	R\$ 14.148	R\$ 606	R\$ 14.754	-41%	-36%
Region 8	R\$ 21.401	R\$ -	R\$ 21.401	00100	R\$ 7.098	R\$ 8.838	R\$ 15.936	-202%	-34%
Region 9	R\$ 17.752	R\$ -	R\$ 17.752	01010	R\$ 8.177	R\$ 6.012	R\$ 14.189	-117%	-25%
Region 10	R\$ 32.487	R\$ -	R\$ 32.487	10100	R\$ 14.153	R\$ 11.184	R\$ 25.337	-130%	-28%
Region 11	R\$ 25.493	R\$ -	R\$ 25.493	11010	R\$ 17.181	R\$ 5.736	R\$ 22.917	-48%	-11%
Region 12	R\$ 19.623	R\$ -	R\$ 19.623	11111	R\$ 19.623	R\$ -	R\$ 19.623	0%	0%
Region 13	R\$ 11.757	R\$ -	R\$ 11.757	01010	R\$ 10.170	R\$ 198	R\$ 10.368	-16%	-13%
Region 14	R\$ 34.332	R\$ -	R\$ 34.332	01010	R\$ 17.397	R\$ 6.708	R\$ 24.105	-97%	-42%
Region 15	R\$ 3.399	R\$ -	R\$ 3.399	11001	R\$ 3.211	R\$ 108	R\$ 3.319	-6%	-2%
Region 16	R\$ 2.021	R\$ -	R\$ 2.021	00010	R\$ 1.406	R\$ 300	R\$ 1.706	-44%	-18%
Region 17	R\$ 8.813	R\$ -	R\$ 8.813	11011	R\$ 8.608	R\$ 66	R\$ 8.674	-2%	-2%
Region 18	R\$ 10.906	R\$ -	R\$ 10.906	00010	R\$ 5.081	R\$ 1.920	R\$ 7.001	-115%	-56%
Region 19	R\$ 18.089	R\$ -	R\$ 18.089	01000	R\$ 11.164	R\$ 2.634	R\$ 13.798	-62%	-31%
Region 20	R\$ 16.053	R\$ -	R\$ 16.053	01000	R\$ 8.677	R\$ 2.724	R\$ 11.401	-85%	-41%
Region 21	R\$ 863	R\$ -	R\$ 863	11111	R\$ 863	R\$ -	R\$ 863	0%	0%
Region 22	R\$ 20.558	R\$ -	R\$ 20.558	00100	R\$ 10.060	R\$ 1.428	R\$ 11.488	-104%	-79%
Total	R\$ 403.404	R\$ -	R\$ 403.404		R\$ 227.423	R\$ 79.692	R\$ 307.115	-77%	-31%

Choosing the best policy for each region leads to great results.



NAÏVE RESULTS

Regions	Allowed days in each scenario		
	No penalty cost	Standard Penalty Cost	High Penalty Cost
Region 1	00001	01010	11110
Region 2	10000	01010	11111
Region 3	00100	00100	10100
Region 4	00100	01010	11111
Region 5	00100	00010	01010
Region 6	10000	10100	10100
Region 7	00100	10100	10100
Region 8	00100	00100	10100
Region 9	00100	01010	11110
Region 10	10000	10100	11111
Region 11	10000	11010	11110
Region 12	10000	11111	11111
Region 13	01000	01010	01010
Region 14	00010	01010	11011
Region 15	01000	11001	11111
Region 16	00010	00010	11111
Region 17	00100	11011	11011
Region 18	00010	00010	00110
Region 19	01000	01000	00100
Region 20	00100	01000	11111
Region 21	10000	11111	11111
Region 22	00100	00100	00100

	Number of allowed days/week		
	No penalty cost	Standard Penalty Cost	High Penalty Cost
	1	2	4
	1	2	5
	1	1	2
	1	2	5
	1	1	2
	1	2	2
	1	1	2
	1	2	4
	1	2	5
	1	3	4
	1	5	5
	1	2	2
	1	2	4
	1	3	5
	1	1	5
	1	4	4
	1	1	2
	1	1	1
	1	1	5
	1	5	5
	1	1	1



THRESHOLD ALGORITHM

Region	M - W - F / 1 - 0 - 1 - 0 - 1			1 - 0 - 1 - 0 - 1 / Threshold			Delta		
	Extra transp. Cost	Penalty Costs	Relevant costs	Extra transp. Cost	Penalty Costs	Relevant costs	Extra transp. Cost	Penalty Costs	Relevant costs
Region 1	R\$ 24.835	R\$ 6.378	R\$ 31.213	R\$ 24.079	R\$ 6.402	R\$ 30.481	-3%	0%	-2%
Region 2	R\$ 16.598	R\$ 10.050	R\$ 26.648	R\$ 16.089	R\$ 10.092	R\$ 26.181	-3%	0%	-2%
Region 3	R\$ 29.132	R\$ 1.062	R\$ 30.194	R\$ 29.132	R\$ 1.080	R\$ 30.212	0%	2%	0%
Region 4	R\$ 10.362	R\$ 7.704	R\$ 18.066	R\$ 9.622	R\$ 7.752	R\$ 17.374	-8%	1%	-4%
Region 5	R\$ 15.445	R\$ 3.186	R\$ 18.631	R\$ 13.383	R\$ 3.318	R\$ 16.701	-15%	4%	-12%
Region 6	R\$ 19.534	R\$ 258	R\$ 19.792	R\$ 19.131	R\$ 264	R\$ 19.395	-2%	2%	-2%
Region 7	R\$ 17.079	R\$ 366	R\$ 17.445	R\$ 17.079	R\$ 366	R\$ 17.445	0%	0%	0%
Region 8	R\$ 19.896	R\$ 228	R\$ 20.124	R\$ 19.896	R\$ 228	R\$ 20.124	0%	0%	0%
Region 9	R\$ 13.496	R\$ 8.586	R\$ 22.082	R\$ 13.283	R\$ 8.598	R\$ 21.881	-2%	0%	-1%
Region 10	R\$ 22.968	R\$ 7.488	R\$ 30.456	R\$ 22.968	R\$ 7.488	R\$ 30.456	0%	0%	0%
Region 11	R\$ 16.142	R\$ 9.378	R\$ 25.520	R\$ 16.142	R\$ 9.378	R\$ 25.520	0%	0%	0%
Region 12	R\$ 13.190	R\$ 20.208	R\$ 33.398	R\$ 13.190	R\$ 20.208	R\$ 33.398	0%	0%	0%
Region 13	R\$ 15.611	R\$ 4.956	R\$ 20.567	R\$ 13.571	R\$ 5.088	R\$ 18.659	-15%	3%	-10%
Region 14	R\$ 27.477	R\$ 4.062	R\$ 31.539	R\$ 27.477	R\$ 4.062	R\$ 31.539	0%	0%	0%
Region 15	R\$ 3.399	R\$ 180	R\$ 3.579	R\$ 3.211	R\$ 192	R\$ 3.403	-6%	6%	-5%
Region 16	R\$ 2.021	R\$ 18	R\$ 2.039	R\$ 2.021	R\$ 24	R\$ 2.045	0%	25%	0%
Region 17	R\$ 14.571	R\$ 6.894	R\$ 21.465	R\$ 13.337	R\$ 6.990	R\$ 20.327	-9%	1%	-6%
Region 18	R\$ 10.293	R\$ 534	R\$ 10.827	R\$ 9.986	R\$ 540	R\$ 10.526	-3%	1%	-3%
Region 19	R\$ 18.089	R\$ 6	R\$ 18.095	R\$ 18.089	R\$ 12	R\$ 18.101	0%	50%	0%
Region 20	R\$ 17.788	R\$ 2.016	R\$ 19.804	R\$ 16.486	R\$ 2.184	R\$ 18.670	-8%	8%	-6%
Region 21	R\$ 863	R\$ 30	R\$ 893	R\$ 863	R\$ 30	R\$ 893	0%	0%	0%
Region 22	R\$ 17.059	R\$ 120	R\$ 17.179	R\$ 17.496	R\$ 156	R\$ 17.652	2%	23%	3%
Total	R\$ 345.849	R\$ 93.708	R\$ 439.557	R\$ 336.533	R\$ 94.452	R\$ 430.985	-3%	1%	-2%

This threshold is more effective in regions with medium demand

In regions with very low demand or very high demand it is not very effective



DECISION TO SHIP EARLY OR LATE

Cost of shipping early (CSE)

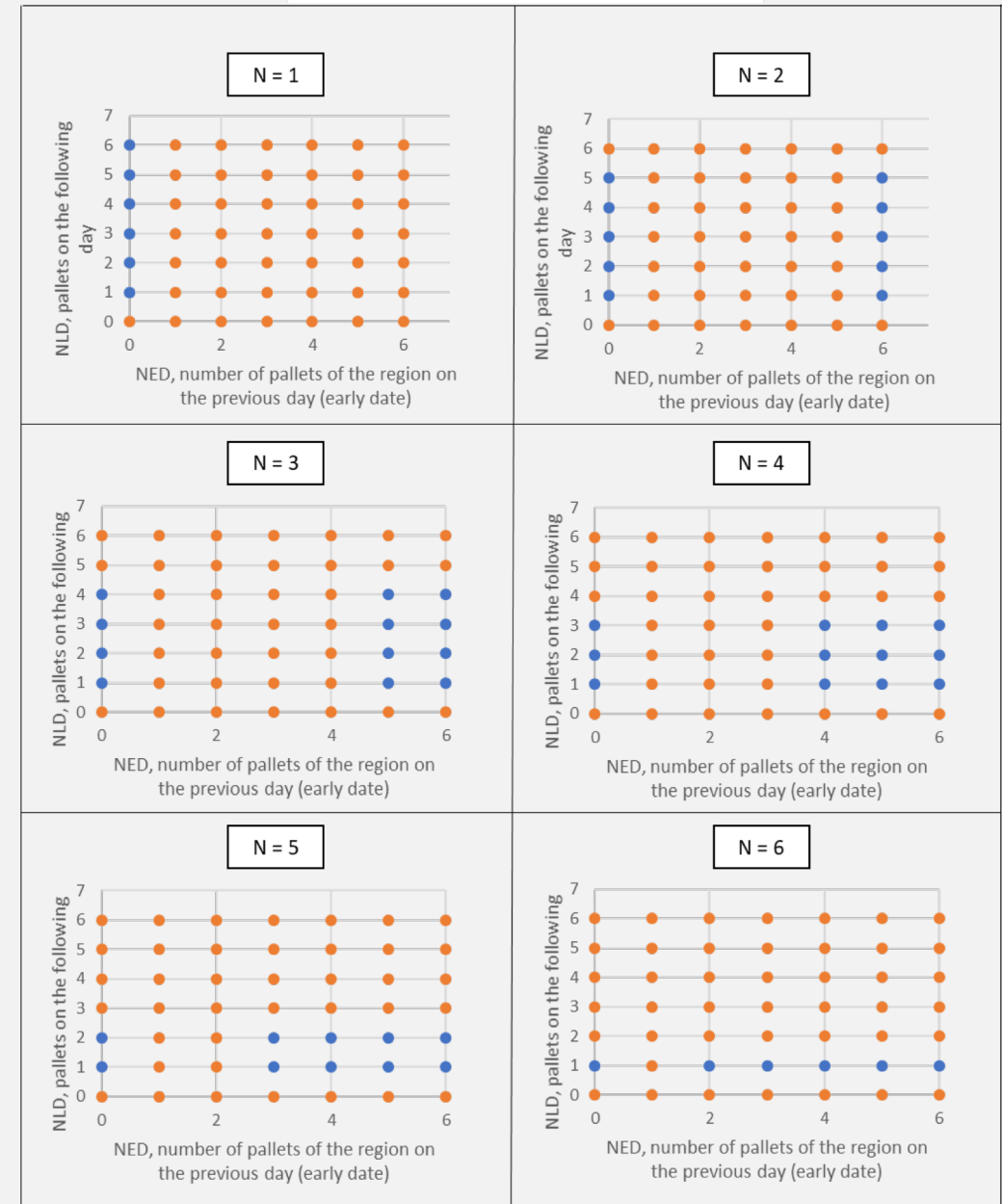
$$CSE = \text{Penalty costs} + \text{transp. costs (earlier day)} + \text{transp. costs (later day)}$$

$$CSE = CED * N * (RF_i - ED) + \text{roundup} \left[\frac{NED + N}{7}, 0 \right] * t + \text{roundup} \left[\frac{NLD}{7}, 0 \right] * t$$

Cost of shipping late (CSL), same as cost of holding an order

$$CLD * N * (LD - RF_i) + \text{roundup} \left[\frac{NLD + N}{7}, 0 \right] * t + \text{roundup} \left[\frac{NED}{7}, 0 \right] * t$$

● SHIP LATE ● SHIP EARLY



AGENDA

Introduction

Literature
review

Method

Results &
discussion

Conclusion



CONCLUSIONS

- 1) Using best policy @ region level: -77% extra transportation costs, total relevant costs -31%.
- 2) Sensitivity analysis to understand how different penalty costs impact the minimum cost solution.
- 3) Analyzed how defining a threshold impacts the result. More efficient technique in regions with medium demand.
- 4) Then we analyzed in more detail the decision of when to ship early or ship late, providing a set of equations to guide this decision.

There are opportunities in modeling delivery policies and the decision to hold or to ship an order. They are easily implementable and bring instant financial rewards.



EVALUATION OF DIFFERENT DELIVERY POLICIES IN THE CEMENT INDUSTRY

Juan Carlos Coloma López and Michel Groenner

Advisor: Dr. Chris Caplice

