Universidad de Monterrey

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UNIVERSIDAD DE MONTERREY

Universidad EAFIT, Medellín, Colombia, July 2018

UNIVERSIDAD EAFIT

Bachelors in:
- Industrial Eng.
- Management Eng.
- Mechanical – Manager Eng.
- Mechatronics Eng.
- Electronic Tech. & Robotics Eng.
- Computational Technologies Eng
- Animation and Digital Effects
- Civil Eng.

~1500 undergraduate students

Departments
- Mathematics & Physics
- Engineering
- Civil Engineering
- Computational Sciences

Master programs in
- Industrial and Systems Eng.
- Product Eng.
- Engineering Management

~120 graduate students

UDEM

DIT - Engineering and Technology Division

DIT at a glance

Å 50 Full time professors
Å 96 part time professors
Å 16 SNI researchers
Å ~420 class groups offered
Å >4.6: EvaProf
Å 25: Av. Group size
Å >97%: Professor attendance
Å 58% students graduated with International experience

DIT's Research in 2017

Å Peer review papers: 38
Å Difusion papers: 11
Å Conference participations: 83
Å Non academic participations: 20
Å Books and Book chapters: 7
Å External funded projects: 12
Å Extension: 6 ($1.5mdp)
Å Patents: 4



Jenny at UDEM

Å 2 years
Å Optimization area: Linear programming and Operations research courses + Design of experiments
Å Advisor: 4 Final projects: all of them awarded in international conferences
Å SNI since 2016

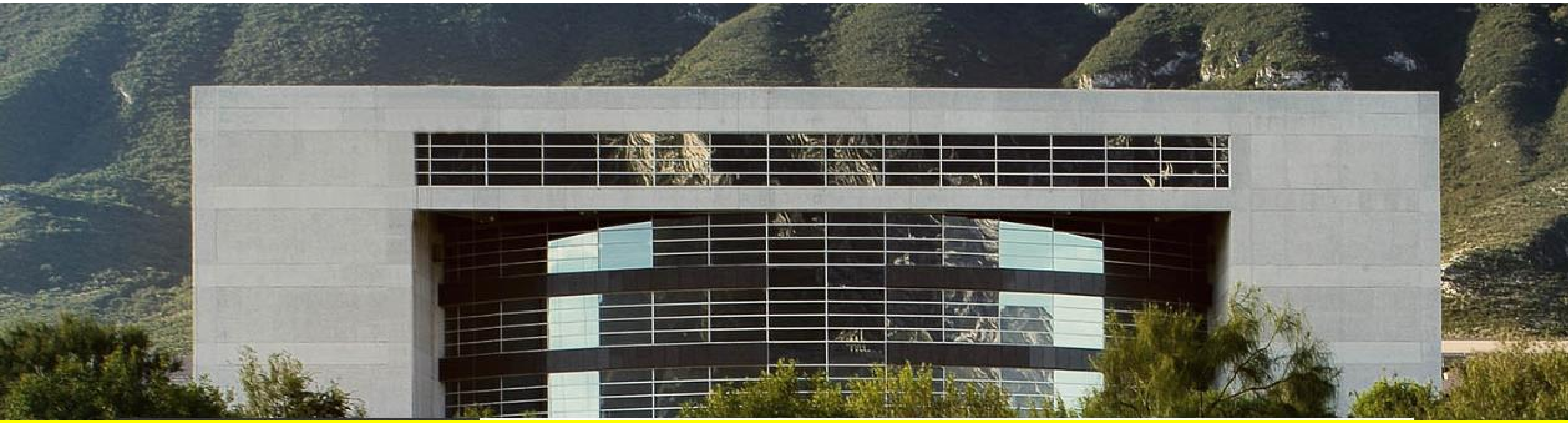
Recent / Current research

Å Eco-driving
Å Driving cycles
Å Logistics & scheduling
Å OR in Health care
Å Sustainable routing

- 4 papers in peer review journals
- 5 conference proceedings
- 2 papers under review

Research with M. Gulnara at EAFIT

- 2 conference proceedings
- Ambulance relocation – in process
- Clustering + Rich VRP – In process



A Comparison of Ambulance Location Models in Two Mexican Cases

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Universidad EAFIT, Medellín, Colombia, July 2018

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A Comparison of Ambulance Location Models in Two Mexican Cases

Contents

- Motivation
- EMS: Emergency Medical Services
- Optimization Models: DSM, ARTM, MEXCLP
- The two cases: Monterrey and Tijuana
- Numerical experimentation and Results
- Conclusions

CRUZ ROJA MEXICANA

MONTERREY

Motivation

- Location of bases for ambulances: Strategic decisions of EMS planning.
- Vast literature: Most of them about European operating conditions. Also in Japan, US, Canada,
- Very few studies in LA: Mexico, Brazil, Colombia
- Mexican situation: Many options to locate them.
- Latin America: No much available data on service quality

Research questions

For the case cities:

ÅHow is the service quality of EMS compared to international standards?

ÅWhich discrete ambulance location model performs better?

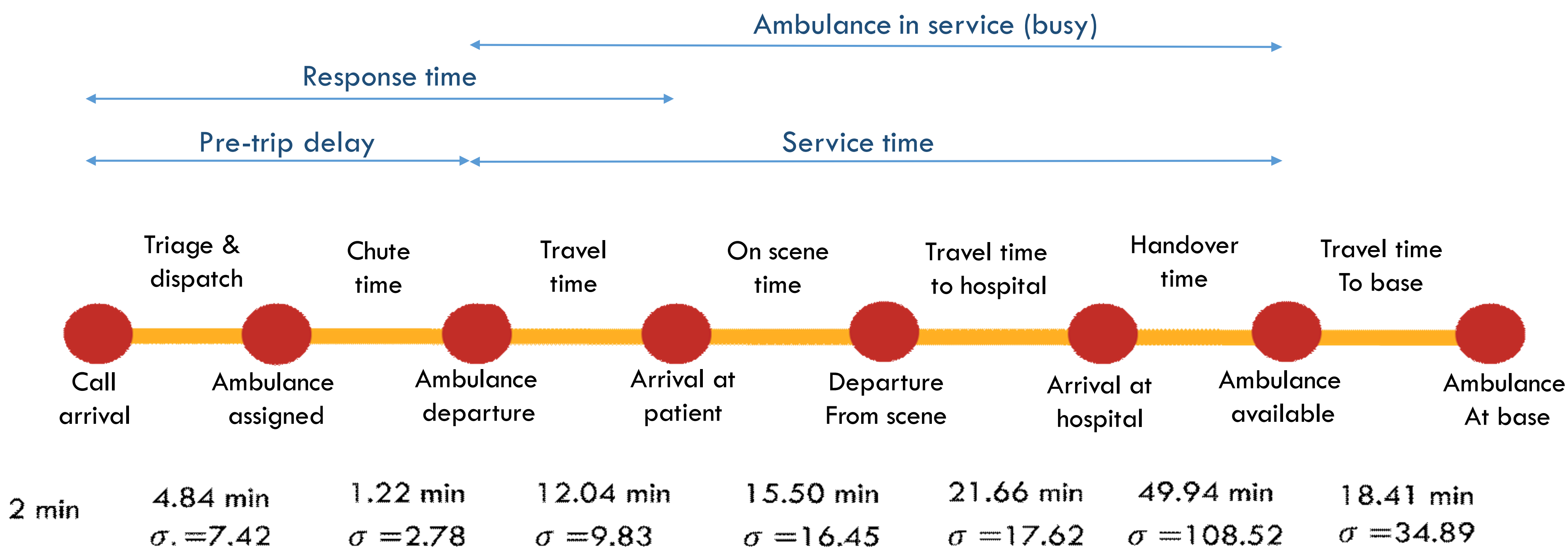
ÅWhat would be the best configuration, given available resources?

ÅWhat suggestions arise for a future dynamic (real-time) location and relocation ambulance system?

EMS: Emergency Medical Services

- The process
- Brief review
- Performance indicators
- Some standards

EMS: Emergency Medical Services



Carranza et al, 2017
Sample taken in sept, 2017.
Mexican Red Cross, Monterrey

van den Berg, 2016

Review on Location Models

- Several recent reviews (Hadiyul et al, 2018, Rodriguez et al, 2017, Reuter-Oppermann, 2017, Aringhieri et al, 2017 Ahmadi-Javid et al, 2017, Li et al., 2011).
- Uncertainty:
  - demand,
  - availability of EMS vehicles, and
  - response times.
- Main KPIs:
  - Response time,
  - single, double or multiple coverage,
  - preparedness level.

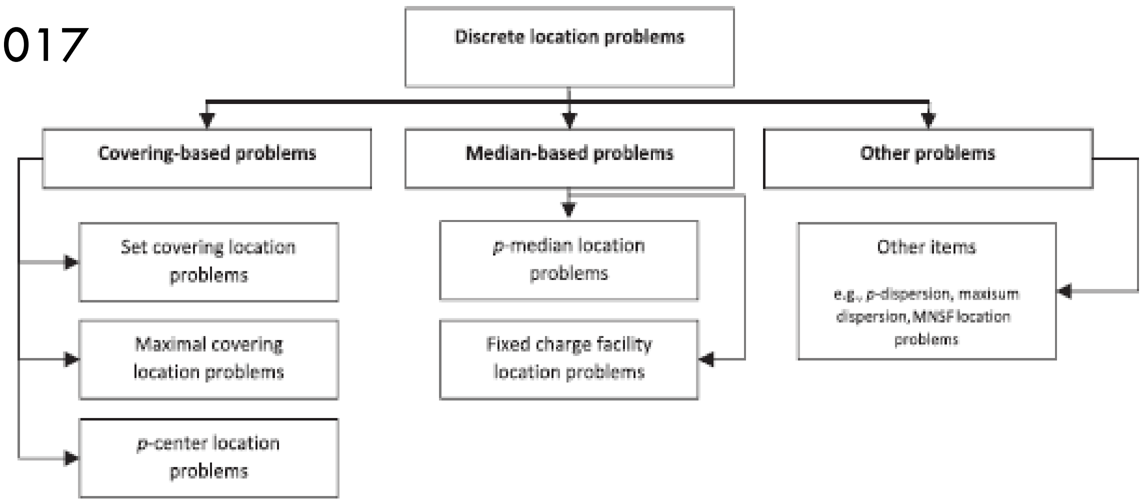


Fig. 1. A classification of discrete location problems.

Ahmadi-Javid et al., 2017

Performance indicators

Response time

- RTT in US: 9 min

  (most common RTT)* [1]
- RTT in UK: 8 min for most critical calls.

Real

- Tijuana, Mexico:

  ART: 14 min, σ = 7 min [3]
- Monterrey, Mexico:

  ART: 19.10 min, σ =12.62 min. [4]

Covering

A given % demand covered within X min

- Usually 10 min, 15 min or 8 min**
- Once or twice or more times.

- 95% call <10 min (The EMS Act of 1973, in [5])

  US Real: 90% life-threatening calls in < 9min.
- UK Std: 75% most critical calls in < 8 min;

  UK Real: 65-75% in 3 cities. [6]
- Germany Std: 95% life- threatening calls in < 15 min; all non life-threatening calls in < 30 min. [6]
- Japan Real: < 5min once: ~60%, twice:~10%, <10 min twice: ~80% [2]

* RTT: Response Time Threshold
** US National Fire Protection Association's recommendation

[1] (Aringhieri et al., 2017)
[2] (Limpattanasiri, 2016)
[3] (Dibene et al., 2017)
[4] (Carranza et al., 2017)
[5] (Li et al., 2011)
[6] (Reuter-Opperman, 2017)

Optimization Models

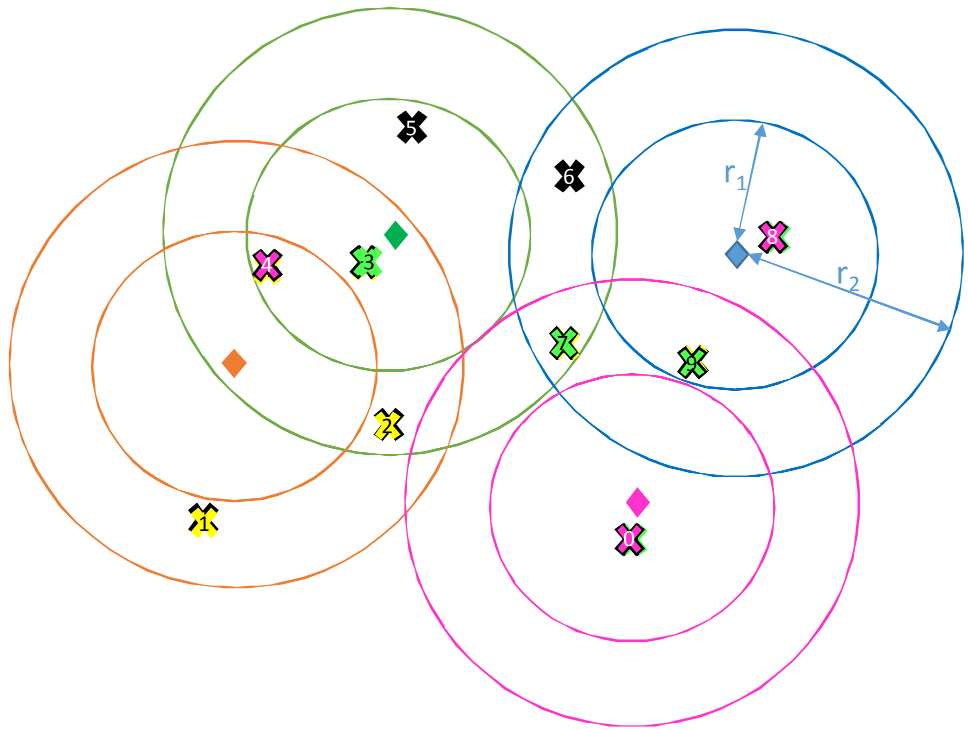
Å DSM
Å ARTM
Å MEXCLP

Coverage, double coverage and response time illustration

100% coverage in r_2:
- Min: 2 bases
- 2 or 3 or 4 & 7 or 9
- or: 1,2,3 or 4 & 7

100% coverage in r_1:
- Min: 3 bases
- 4, 8 or 9 & 0

min response time:
- 1 base: 7
- 2 bases: 3, 9
- 3 bases: 3, 8 & 0



Some common notation

Sets:

$i \in I$: demand zones $\{1,2,3,\cdots,D\}$
$j \in J$: potential bases $\{1,2,3,\cdots,p\}$
$k \in K$: ambulances $\{1,2,3,\cdots,A\}$
$s \in S$: service types $\{1,2,3\}$
$t \in T$: time slots $\{1,2,3,\cdots T\}$

Variables:

$$y_{ikt} = \begin{cases} 1 \text{ if demand point } i \text{ is covered } k \text{ times at time interval } t, \text{within } r_1 \\ 0 \text{ otherwise} \end{cases}$$

$$x_j = \begin{cases} 1 \text{ if a base is open at location } j \\ 0 \text{ otherwise} \end{cases}$$

u_{jt} = Number of identical ambulances assigned at base j at time t.
Z_{DC}= Weighted double coverage

Parameters:

α: Minimal coverage in r_1 (%)
W_{its}: Weighted demand in zone i, for service type s, at time t
v_j: Maximum number of ambulances at location j

$$a_{ij}^1 = \begin{cases} 1 \text{ if location } j \text{ covers demand point } i \text{ within } r_1 \\ 0 \text{ otherwise} \end{cases}$$

$$a_{ij}^2 = \begin{cases} 1 \text{ if location } j \text{ covers demand point } i \text{ within } r_2 \\ 0 \text{ otherwise} \end{cases}$$

DSM: Double Standard Model

Sets:

$i \in I$: demand zones $\{1,2,3,\cdots,D\}$
$j \in J$: potential bases $\{1,2,3,\cdots,p\}$
$k \in K$: ambulances $\{1,2,3,\cdots,A\}$
$s \in S$: service types $\{1,2,3\}$
$t \in T$: time slots $\{1,2,3,\cdots T\}$

Variables:

$$y_{ikt} = \begin{cases} 1 \text{ if demand point } i \text{ is covered } k \text{ times} \\ \quad \text{at time interval } t, \text{within } r_1 \\ 0 \text{ otherwise} \end{cases}$$

$$x_j = \begin{cases} 1 \text{ if a base is open at location } j \\ 0 \text{ otherwise} \end{cases}$$

$$\max Z_{DC} = \sum_i \sum_s \sum_t (w_{its}\, y_{i2t})$$

Subject to:

$$\sum_j a_{ij}^2 u_{jt} \geq 1 \quad \forall\, i,t$$
$$\sum_s \sum_i w_{its} y_{i1t} \geq \alpha \sum_s \sum_i w_{its} \quad \forall t$$
$$y_{i,k+1,t} \geq y_{ikt} \quad \forall i,k,t$$
$$\sum_j a_{ij}^1 u_{jt} \geq y_{i1t} + y_{i2t} \; \forall i,t$$
$$u_{jt} \leq v_j\, x_j \quad \forall j,t$$
$$\sum_j u_{jt} = A \quad \forall t$$
$$\sum_j x_j \leq p$$
$$x_j \in \{0,1\} \quad \forall j; \qquad y_{ikt} \in \{0,1\} \quad \forall i,t$$
$$u_{jt} \geq 0, integer \quad \forall j,t$$

Gendreau et al (1997)

ARTM: Average Response Time Model

$\min Z_{RT} = \sum_i \sum_s \sum_t \sum_j w_{its}\, tp_{ij}\, y_{ijt}$

Subject to:

$\sum_j y_{ijt} = 1 \quad \forall i, t$

$y_{ijt} \leq x_j \quad \forall i, j, t$

$u_{jt} \leq v_j\, x_j \quad \forall j, t$

$\sum_j u_{jt} = A \quad \forall t$

$\sum_j x_j \leq p$

$x_j \in \{0,1\} \quad \forall j;$

$u_{jt} \geq 0, integer \quad \forall j, t$

$y_{ijt} \in \{0,1\} \quad \forall i, j, t$

Additional Parameters:

tp_{ij}: Response time from location j to point i.

Additional Variables:

$y_{ijt} = \begin{cases} 1 \text{ if the open base } j \text{ is the nearest opened base to demand point } i \text{ at time } t \\ 0 \text{ otherwise} \end{cases}$

Z_{RT}: Average response time

Comparison of Location Models. Díaz, J, Granda, E., Villarreal, B., Frutos, G., 2018

P-median: ReVelle and Swain, 1989
Dzator and Dzator, 2013

MEXCLP: Mean Expected Covering Location Problem

$$\max Z_{XC} = \sum_i \sum_s \sum_t w_{its} \sum_k q^{k-1} (1-q)\, y_{ikt}$$

Subject to:

$$\sum_k y_{ikt} = \sum_j a_{ij}^1 u_{jt} \quad \forall i, t$$

$$y_{i,k+1,t} \geq y_{2ikt} \quad \forall i, k, t$$

$$u_{jt} \leq v_j x_j \quad \forall j, t$$

$$\sum_j u_{jt} = A \quad \forall t$$

$$\sum_j x_j \leq p$$

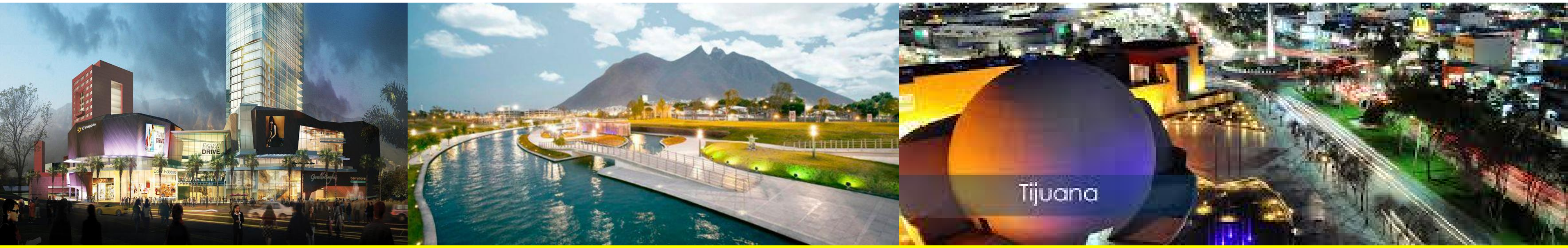
$$x_j \in \{0,1\} \quad \forall j; \quad y_{ikt} \in \{0,1\} \quad \forall i, t$$

$$u_{jt} \geq 0, integer \quad \forall j, t$$

Additional Parameters:
q: Probability that an ambulance is busy (or not available/ not working) within r_1.

Additional Variables:
Z_{XC}: Expected coverage

Comparison of Location Models. Díaz, J, Granda, E., Villarreal, B., Frutos, G., 2018



Two Mexican Cases: Monterrey and Tijuana

Å Demand zones

Å Potential base locations

Å Demand behavior and scenarious

Å Travel time

Monterrey

Å Capital of the northeastern state of Nuevo Leon, in Mexico.

Å Third-largest metropolitan area.

Å Metropolitan area >5,300 km^2 and >4.7 million inhabitants

Villarreal, B., Frutos, G., 2018

(INEGI, 2015).

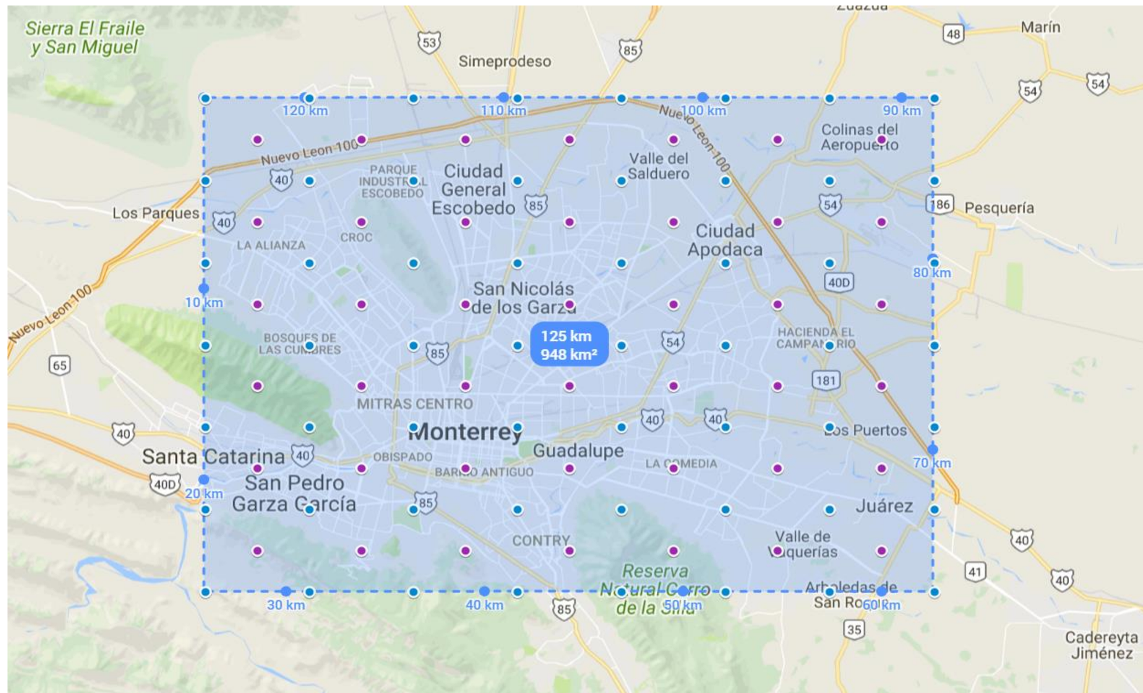
Monterrey

Å 42 equal quadrants

Å ~ 23km^2 each

Å Each demand zone corresponds to a quadrant.

Demand zones



(INEGI, 2015).

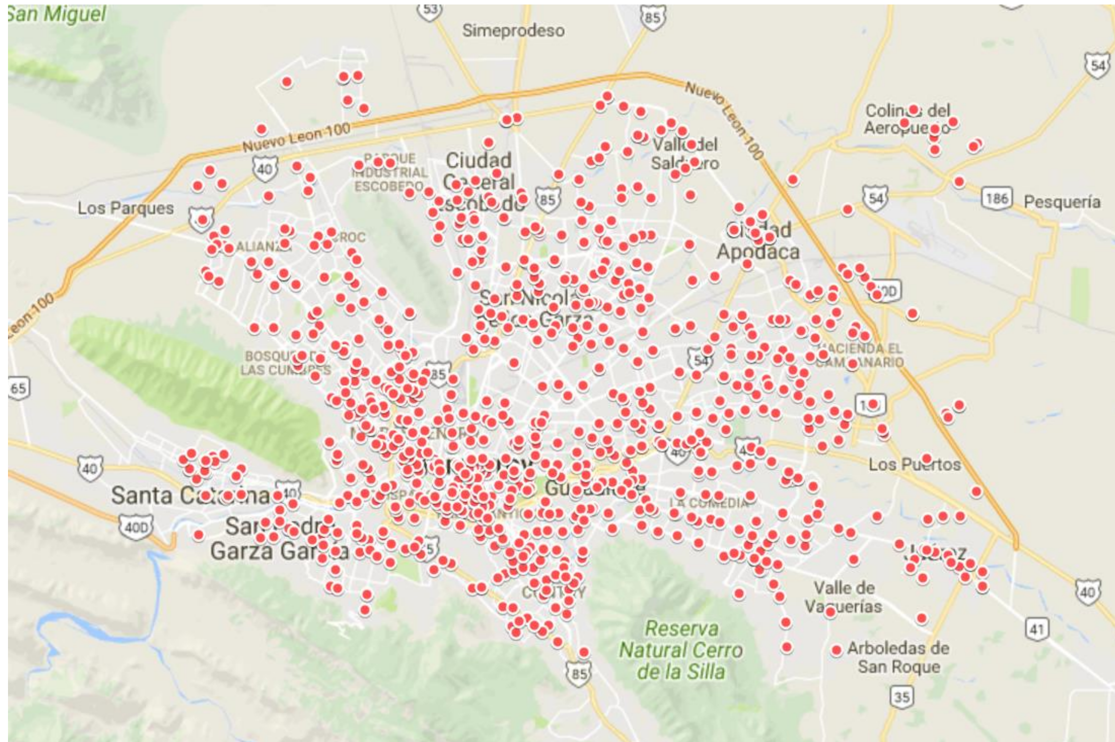
Monterrey

Å Convenience stores all over the city.

Å Each potential base with basic features: space, electricity, etc.

Å 884 possible sites

Potential base locations



(INEGI, 2015).

Tijuana

Å The largest city on the Baja California Peninsula.

Å Located at the northwestern of Mexico, next to the US border.

Å Metropolitan area >1,390 km2 and 1.8 million inhabitants

(INEGI, 2015).

Comparison of Location Models. Díaz, J, Granda, E., Villarreal, B., Frutos, G., 2018

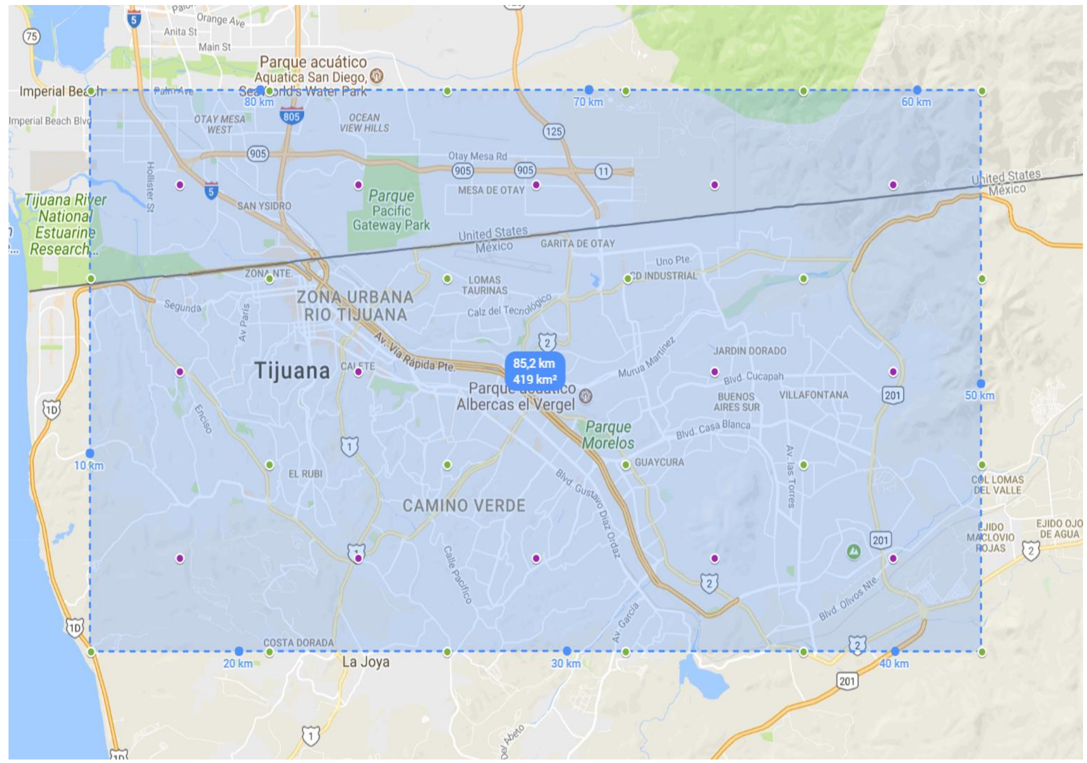
Tijuana

Å 15 equal quadrants

Å ~ 25 km^2 each

Å Each demand zone corresponds to a quadrant.

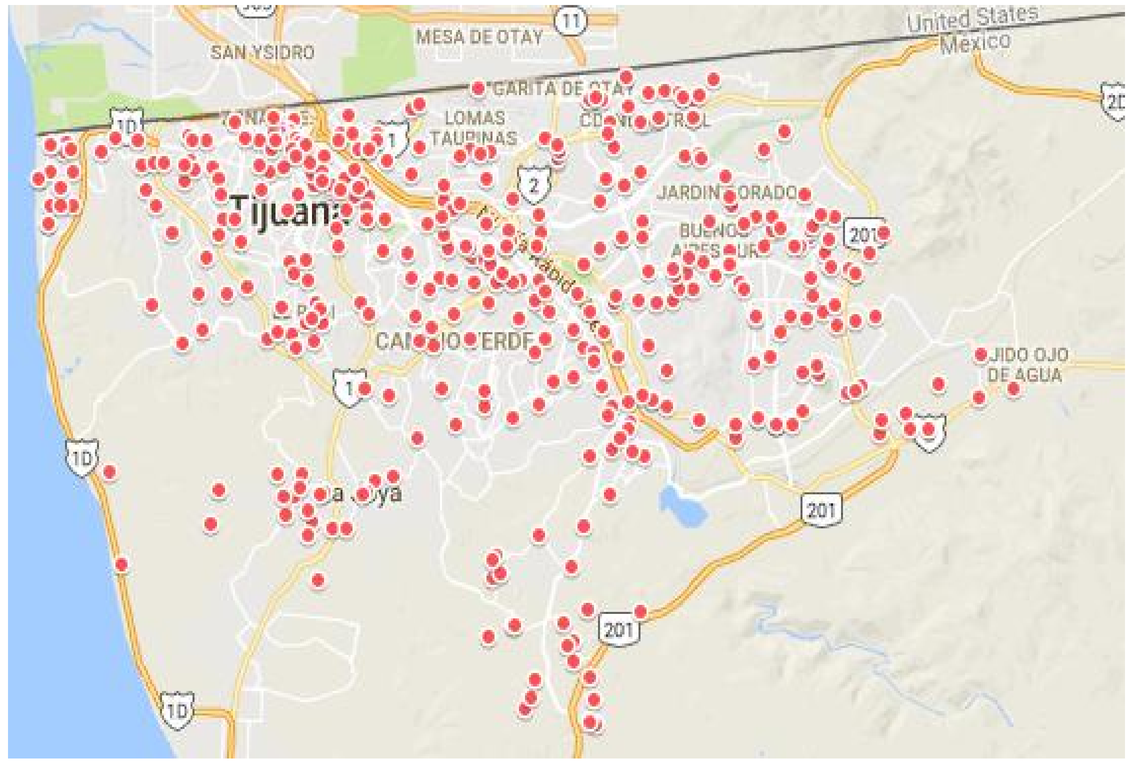
Demand zones



(INEGI, 2015).

Tijuana

Potential base locations



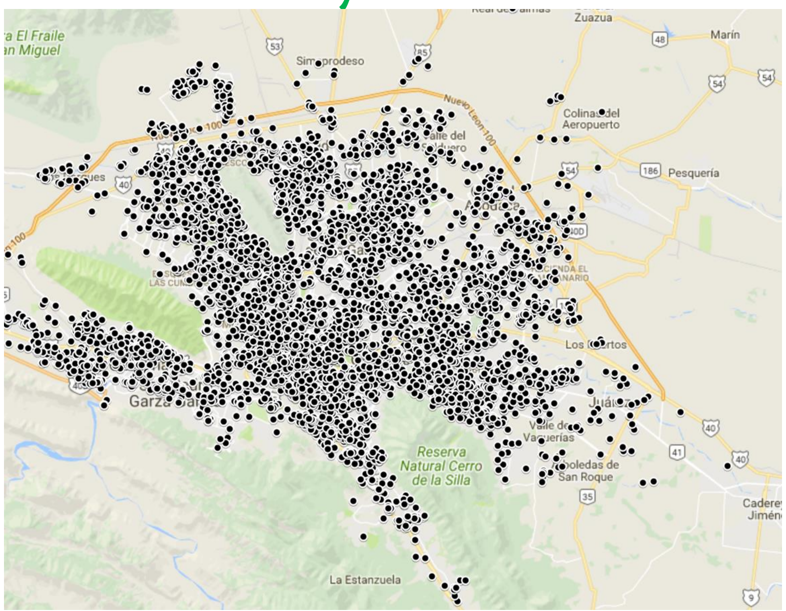
Å Convenience stores all over the city.

Å Each potential base with basic features: space, electricity, etc.

Å 434 possible sites

Demand Behavior for both cities

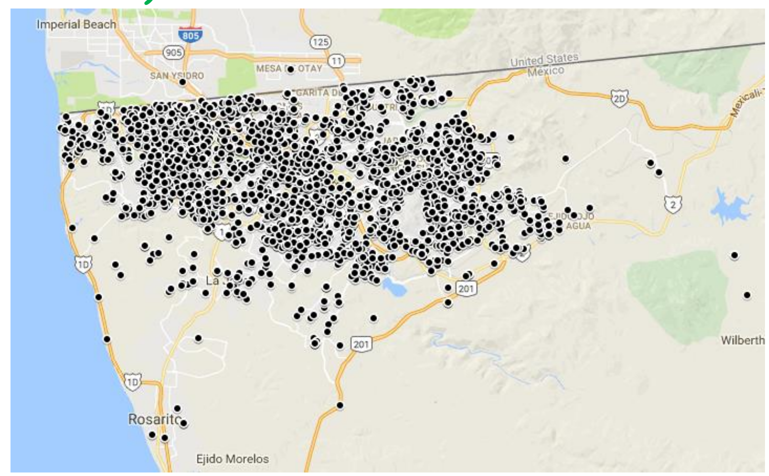
Monterrey



Å 14,368 calls. Red Cross of Monterrey

Å November 2016 to April 2017.

Tijuana



Å 10,176 calls. Red Cross of Tijuana

Å January 1 to August 31, 2014.

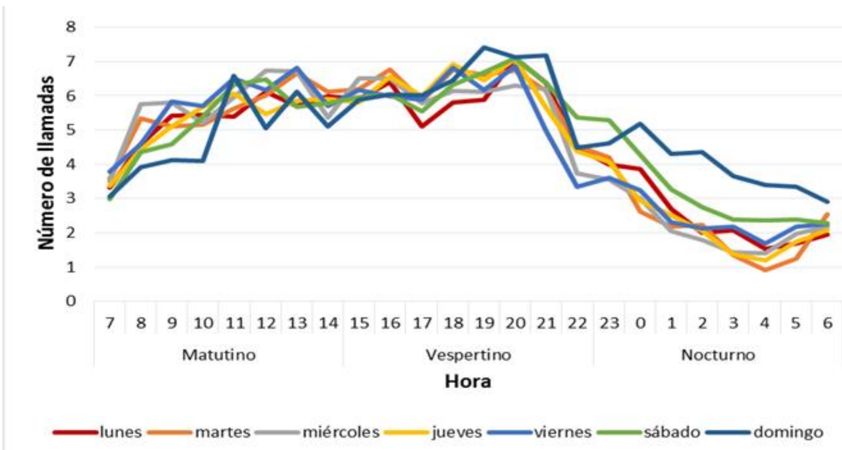
GPS location and priority levels of each call (Siren, Silent Urgency, Make the service brief).

Demand Scenarios and Travel Times

Monterrey and Tijuana

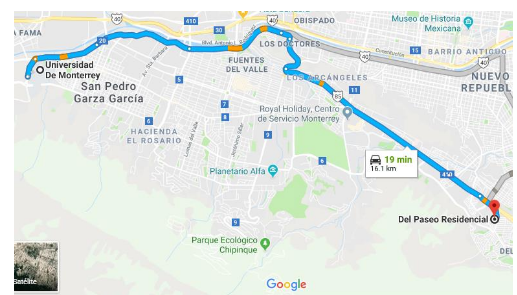
ÅScenarios:

Å Morning, afternoon, night, and an overall case.



ÅTravel time:

Average speed using Google Maps and its forecast of average transfer times between strategic points in the city.



Comparison of Location Models. Díaz, J, Granda, E., Villarreal, B., Frutos, G., 2018

Numerical Experimentation

- Settings
- Performance indicators
- Results

Numerical experimentation

Experimentation setting

ÅModels: in GAMS 23.5 - CPLEX

ÅStandard laptop

ÅPost-processing in Matlab or GAMS.

ÅParameters

- Å$\square_{\square}$ = 15 minutes, $\square_{\square}$ = 30 minutes
- Å$\square$ = 0.7
- Å$\square$ = 20 for Tijuana and $\square$ = 40 for Monterrey
- Å$\square$ = 6, 7, … , $\square$
- Å4 scenarios (am, pm, night, **day**)

Erkut et al., 2009

Numerical experimentation

Calculation of q

Å□(□, □) is the Erlang Loss Function which measures the fraction of lost calls in an M/G/A/A queueing system

$$q = [\lambda(1 - B(\rho, A)\tau(u)]/A \qquad B(\rho, A) = \left[{\rho^A}/{A!}\right] / \left[\sum_{i=0}^{A} {\rho^i}/{i!}\right]$$

TIJUANA				MONTERREY			
λ	$E(\tau)$ [min]	q	Max A	λ	$E(\tau)$ [min]	q	Max A
0.022	90.04	[0.09-0.29]	[6-20]	0.055	85.98	[0.12-0.63]	[6-40]

Erkut et al., 2009
Dibene et al., 2017

Numerical experimentation

Performance measures

Å***Coverage related criteria:***

Å% of locations covered once, twice, and three times within ⍰. (equity).

Å% weighted demand covered once, twice (DSM), and three times within ⍰.

Å% of locations and weighted demand covered once within 10 min and ⍰ = 30 min

Å***Response time related criteria:***

Åmaximum response time,

ÅAverage response time (ARTM)

Å***Evolution as A increases***

Å***Current capacity performance***

Results…on coverage

		TIJUANA			MONTERREY		
Criterion	**Description**	**DSM**	**ARTM**	**MEXCLP2**	**DSM**	**ARTM**	**MEXCLP2**
1	Single location coverage	91.6%	80.4%	**96.9%**	86.3%	73.6%	**84.9%**
2	Double location coverage	**87.1%**	26.2%	81.3%	**74.8%**	38.8%	66.0%
3	Triple location coverage	12.0%	9.8%	**61.8%**	4.6%	8.5%	**40.5%**
4	Single Demand Coverage	99.7%	96.4%	**100.0%**	94.9%	94.2%	**96.7%**
5	**Double Demand Coverage**	**98.6%**	46.6%	96.7%	**88.4%**	63.6%	87.8%
6	Triple Demand Coverage	43.9%	20.6%	**85.5%**	7.1%	20.5%	**66.2%**

ÅDSM better in 2Cov, not significantly better than MEXCLP

ÅDSM also better in 2Loc-Cov, not much than MEXCLP

ÅMEXCLP better in 1Cov and 3Cov, both demand and location

ÅARTM worst in all coverage: though 1Cov is acceptable, 2Cov is deficient, and 3Cov is the worst.

Results… on others

		TIJUANA			MONTERREY		
Criterion	**Description**	**DSM**	**ARTM**	**MEXCLP2**	**DSM**	**ARTM**	**MEXCLP2**
7	Max. Response time (min)	27.94	30.81	28.62	29.72	44.69	59.18
8	**Avg. Response time (min)**	11.88	**6.58**	12.21	11.82	**10.41**	13.55
9	**z_ExpCov**	0.976	0.868	**0.984**	0.866	0.816	**0.897**
10	10 min threshold	30%	77%	19%	36%	56%	29%
11	30 min threshold	100%	100%	100%	100%	96%	94%

ÅARTM: ~60% ART of others, and better in 10 min 1Cov

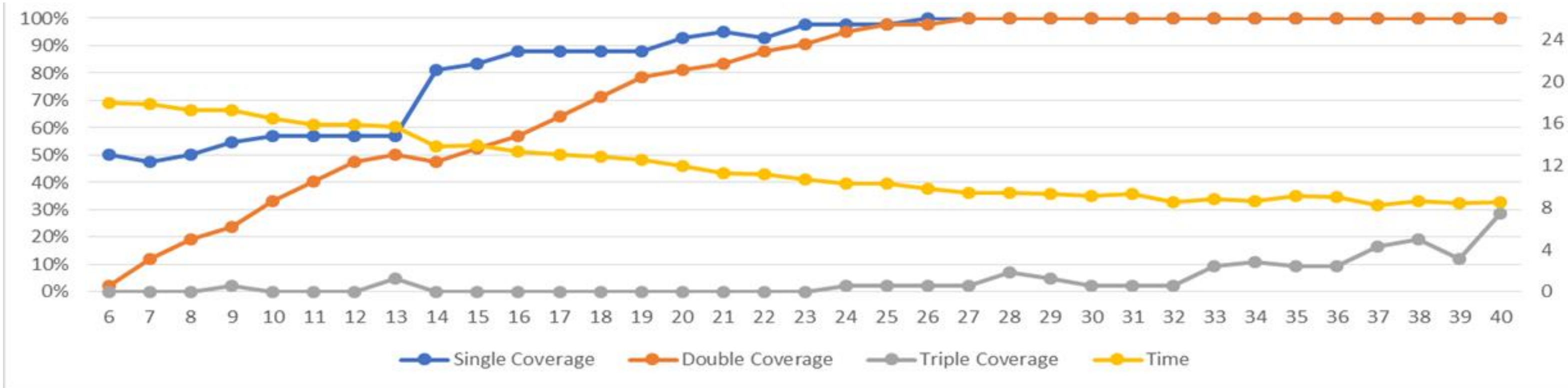
ÅMEXCLP thought better in expected coverage (as expected), not much than DSM.

ÅDSM and ARTM similar! With no dominated solutions (Covs and ExpCov), DSM lightly better in ARTs.

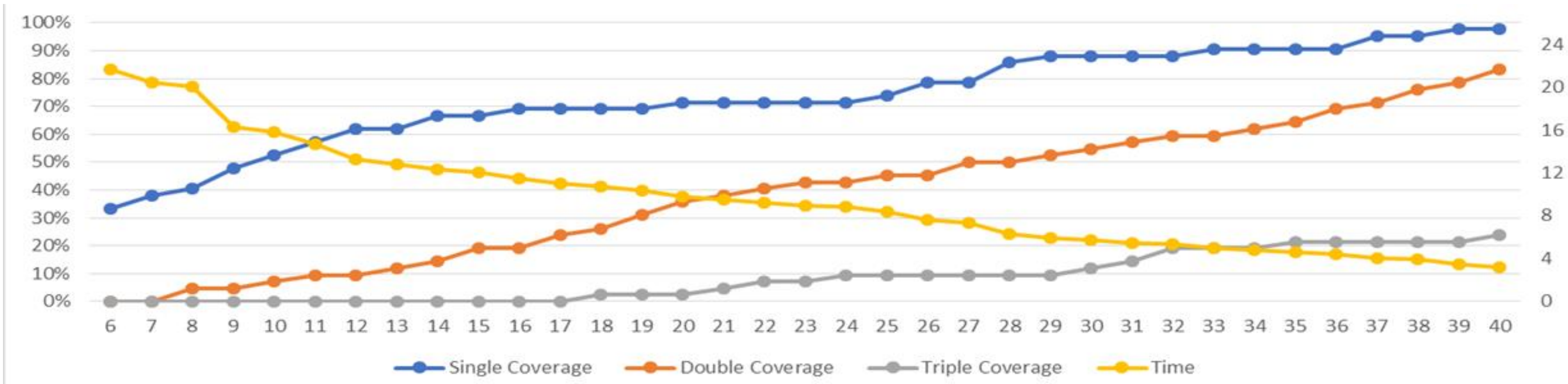
1, 2, and 3 Coverage + response time for different number of ambulances

Monterrey case

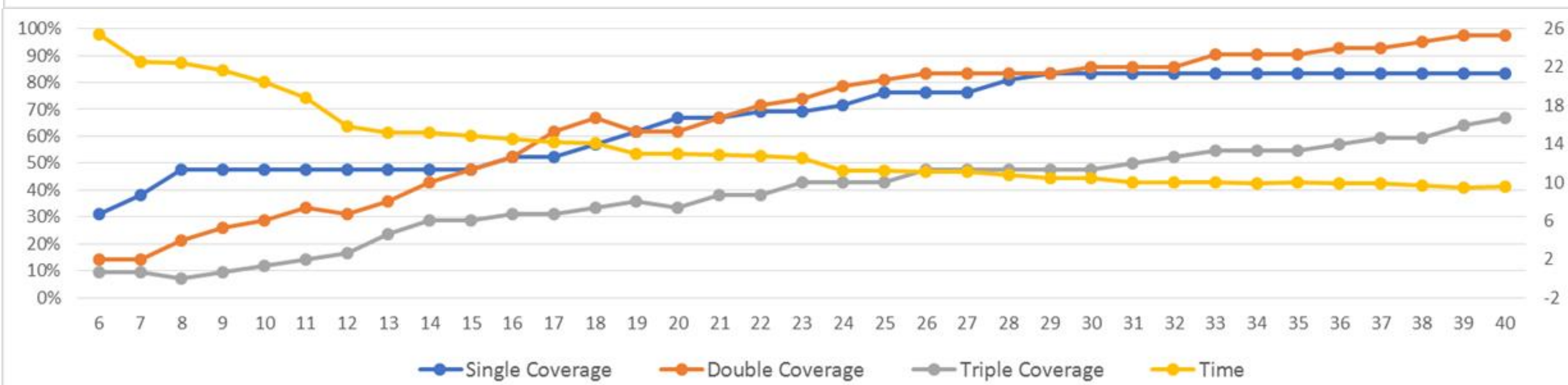
DSM



ARTM



MEXCLP

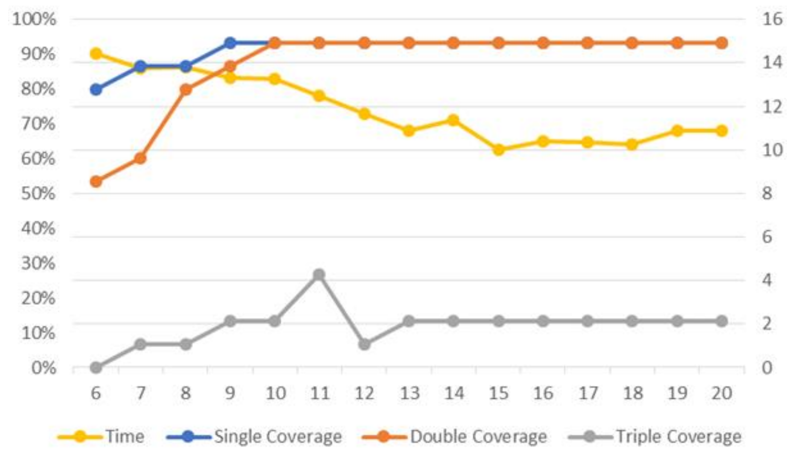


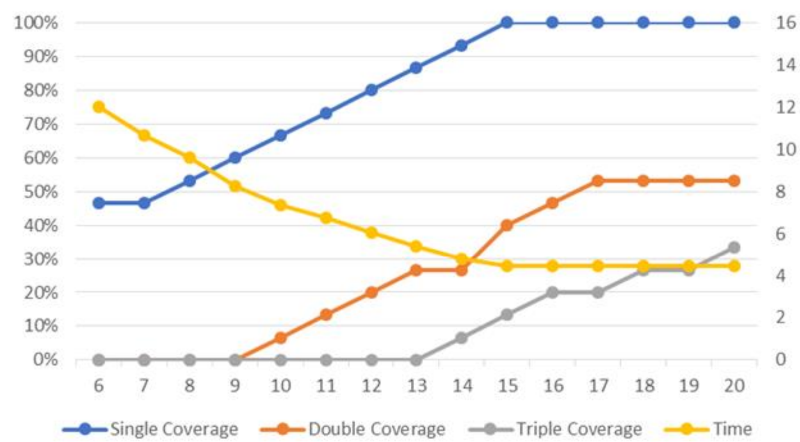
>90% 2Cov:
DSM: 23 amb (10.7 min)
ARTM: Never
MEXCLP: 33 amb (10 min)

1, 2, and 3 Coverage + response time for different number of ambulances

Tijuana case

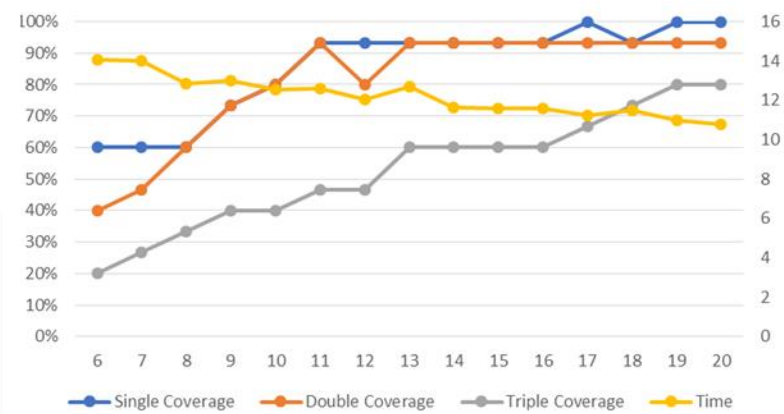
DSM





MEXCLP

Better backup coverage



ARTM

>90% 2Cov:
DSM: 10 amb (13.3 min)
ARTM: Never
MEXCLP: 11 amb (12.6 min)

Results – Current capacity

Performance indicator	TIJUANA (A=8 ambulances)			MONTERREY (A = 14 ambulances)		
	DSM	ARTM	MEXCLP	DSM	ARTM	MEXCLP
Response time (min)	14	10	18	13.8	12.3	15.2
Single zone coverage	87%	53%	60%	81%	67%	43%
Double zone coverage	84%	0%	60%	48%	14%	43%

- DSM performs better in coverage: both cities, both types (demand and location), and in 1Cov, 2Cov, and 3Cov.
- Differences with ARTM in terms of ART, suggests potential improvements of O.F. for DSM (multi-objective)
- Two cases: not enough to see correlation among A, city size, and demand.

Conclusions

Service Quality

For Monterrey & Tijuana:

ÅART=14 min

Å87% (& 81%) calls can be reached within 15 min. (DSM)

Best Models

- Current capacity: DSM
- DSM: in general
- MEXCLP: only best in multiple coverage
- ARTM: bad coverage performance

Best Configuration

Monterrey

- DSM: 20 veh: 12 min, >90% once, 80% twice

Tijuana

- DSM: 10 veh: 90% once, 90% twice, 13min

Recommendations

- DSM + RT or ARTM + backup coverage
- Pay attention to ů

Conclusions and further work

- Done: comparison based on LA real data
- Extensions: different service priorities, zone coverage
- Further: priority analysis, combining models, multiperiod, continuous (dynamic) location



Thank you

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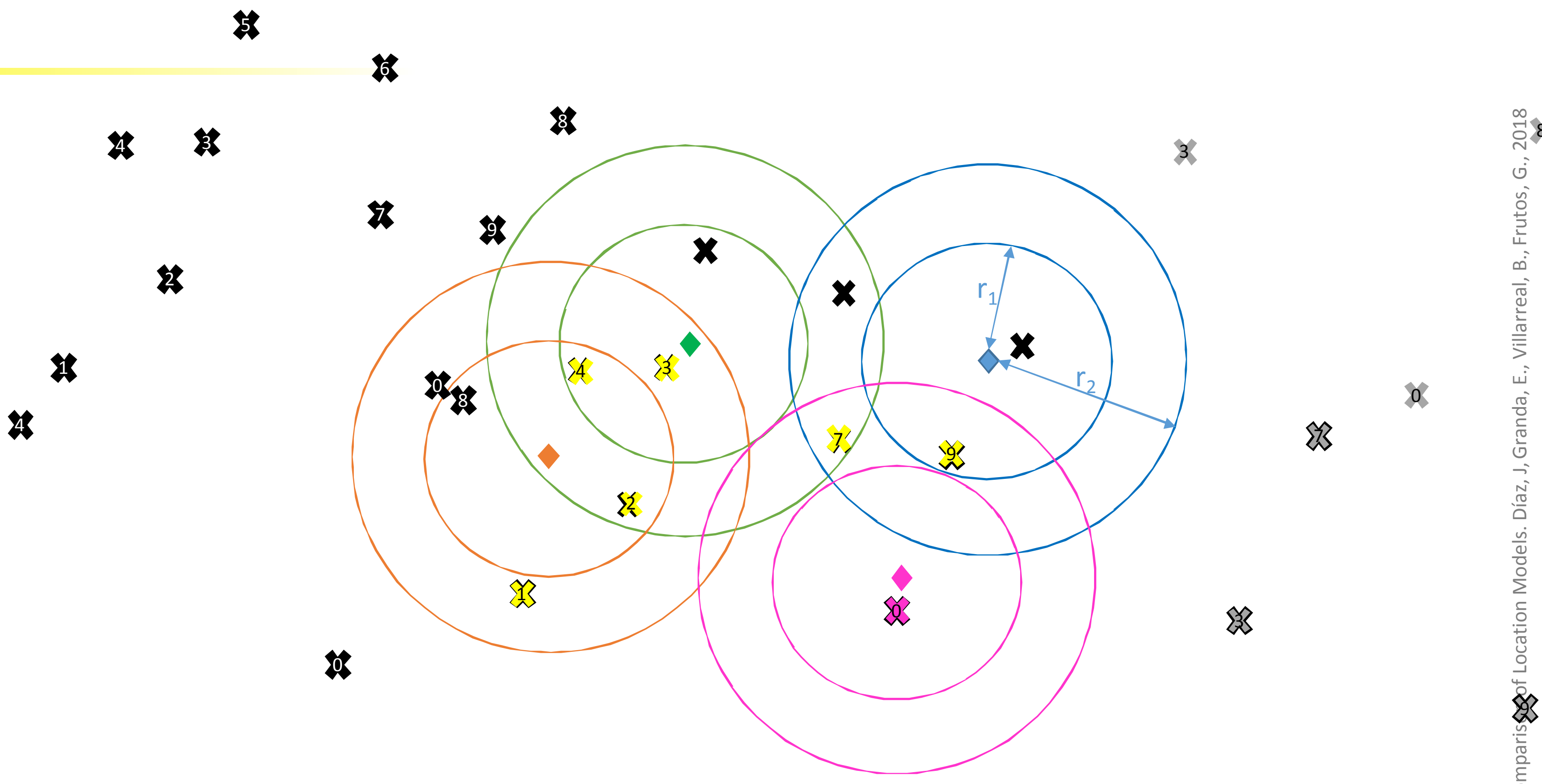
Universidad de Monterrey, Monterrey, Nuevo Leon, Mexico

Coverage, double coverage and response time illustration



Results

		TIJUANA			MONTERREY		
Criterion	**Description**	**DSM**	**ARTM**	**MEXCLP2**	**DSM**	**ARTM**	**MEXCLP2**
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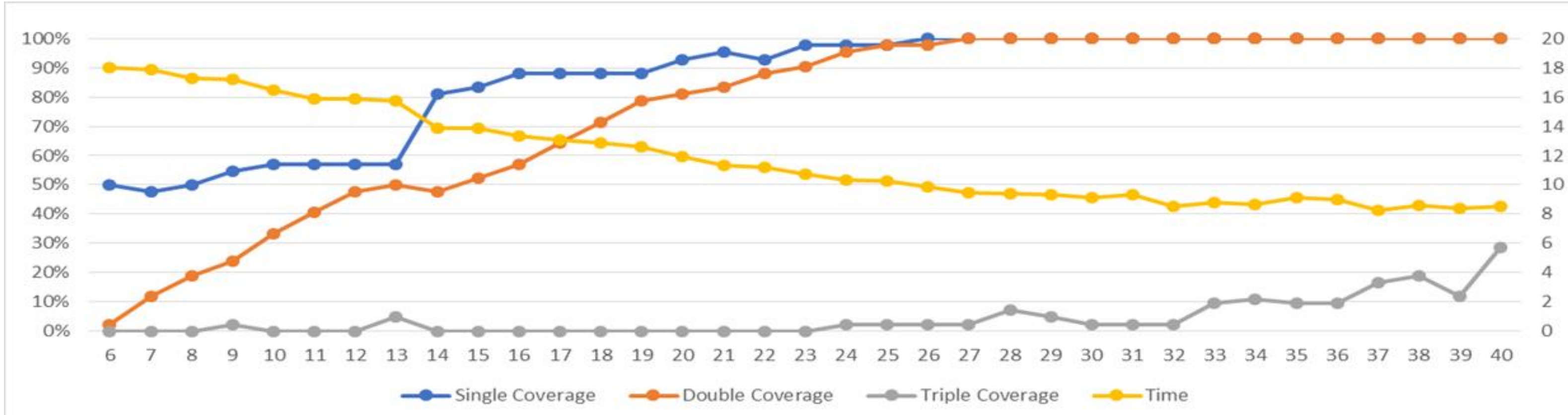
7	Max. Response time (min)	27.94	30.81	28.62	29.72	44.69	59.18
8	**Avg. Response time (min)**	11.88	**6.58**	12.21	11.82	**10.41**	13.55
9	**z_ExpCov**	0.976	0.868	**0.984**	0.866	0.816	**0.897**
10	10 min threshold	30%	77%	19%	36%	56%	29%
11	30 min threshold	100%	100%	100%	100%	96%	94%

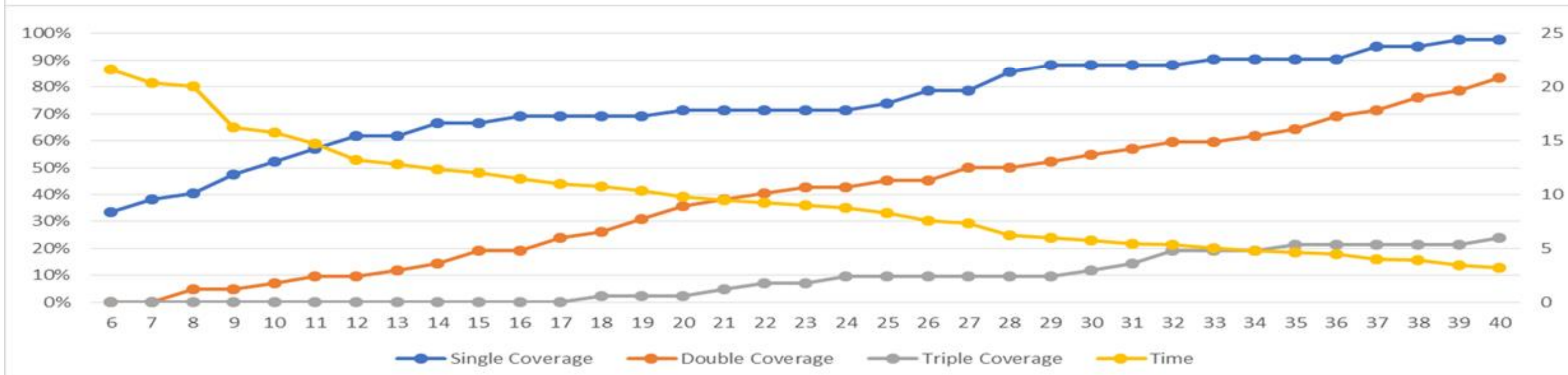
Location Coverage versus response time for different number of ambulances

Monterrey case

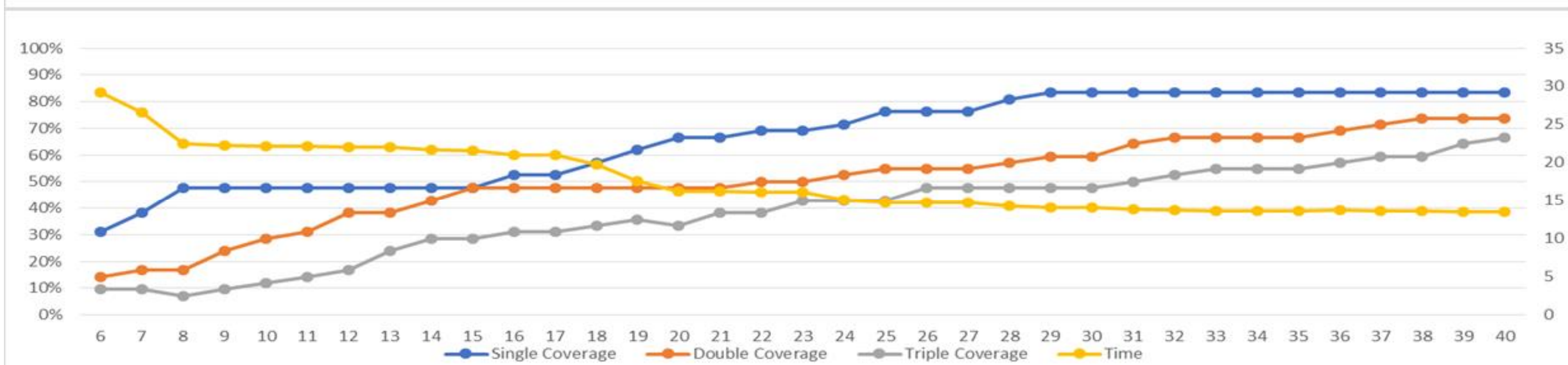
DSM



ARTM



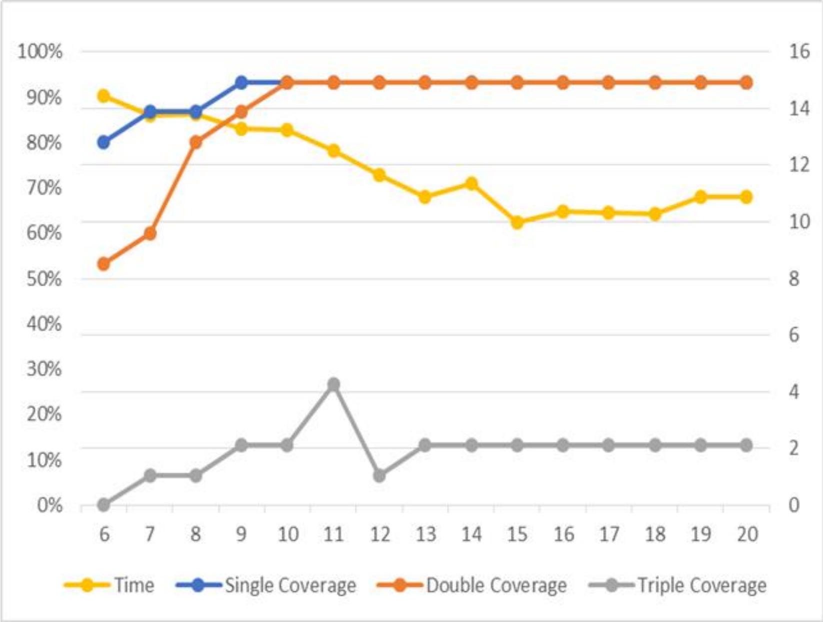
MEXCLP



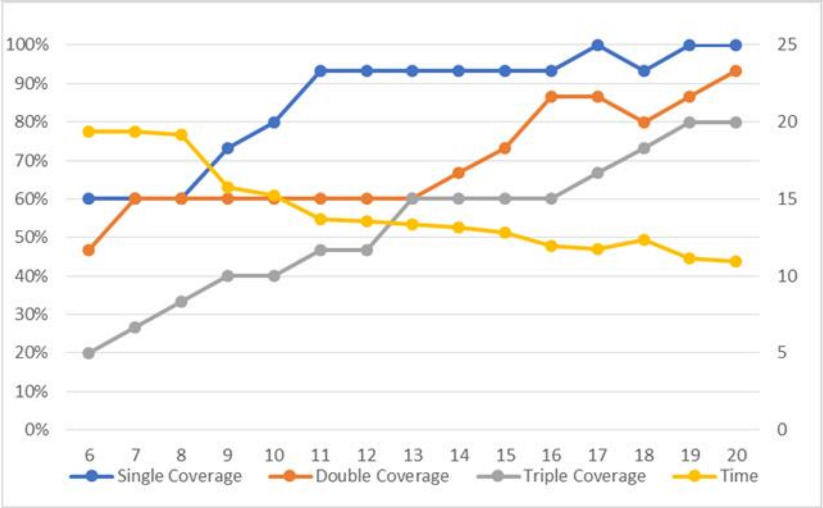
Location Coverage versus response time for different number of ambulances

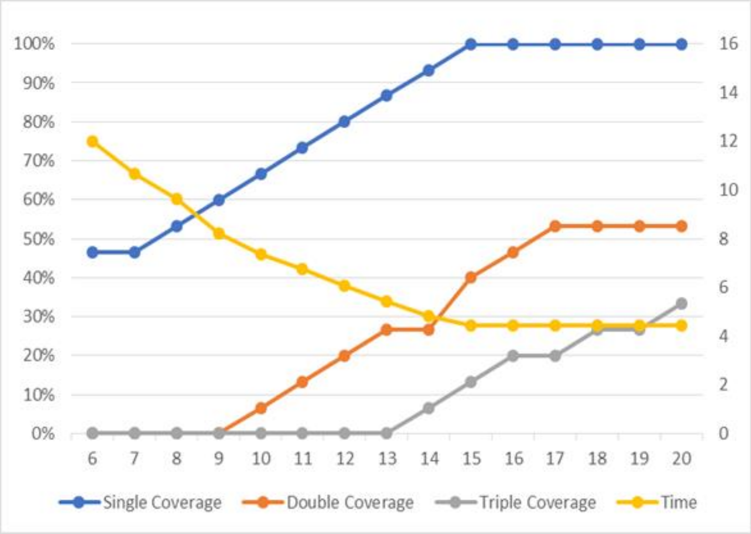
Tijuana case

DSM



ARTM





MEXCLP