Better together: Simulation and Optimization work better together

Idalia Flores
Facultad de Ingeniería, UNAM

30 Anniversary Symposium:the influence and use of simulation in transport industries

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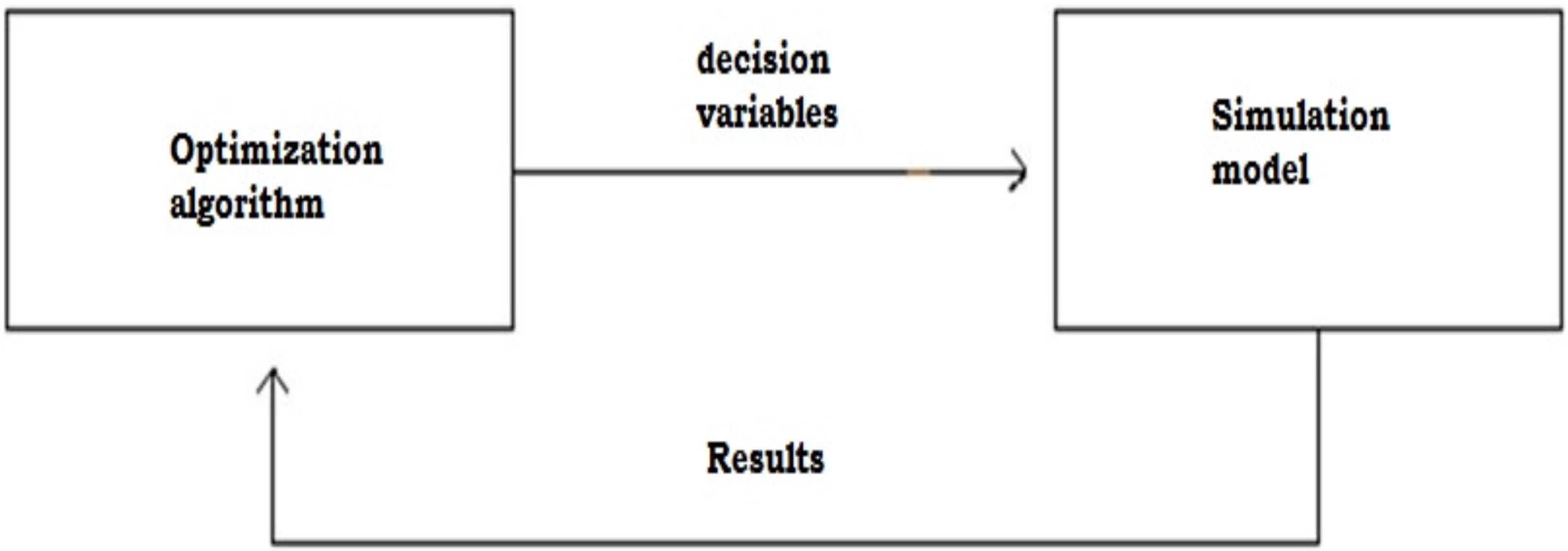
Introduction

- We present here a hybrid methodology that uses optimization and simulation techniques to analyze different cases in transport and to be able to find some that require optimal solutions

Objective

To design a flexible methodology to analyze, evaluate and optimize transport processes and services through the combined use of optimization and simulation techniques

Relationship simulation and optimization



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Background

Since its inception, simulation teams have sought to optimize the problems they solve:

- 1995 Promodel includes SimRunner with evolutional algorithms.
- 2004 Arena includes Optquest with scattered search algorithms.
- 2010 Simio includes OptQuest that uses metaheuristic procedures, including Tabu Search, Neural Networks, Scatter Search, and Linear/Integer Programming, into a single composite method.

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Methodology

- Drawbacks if they work separately

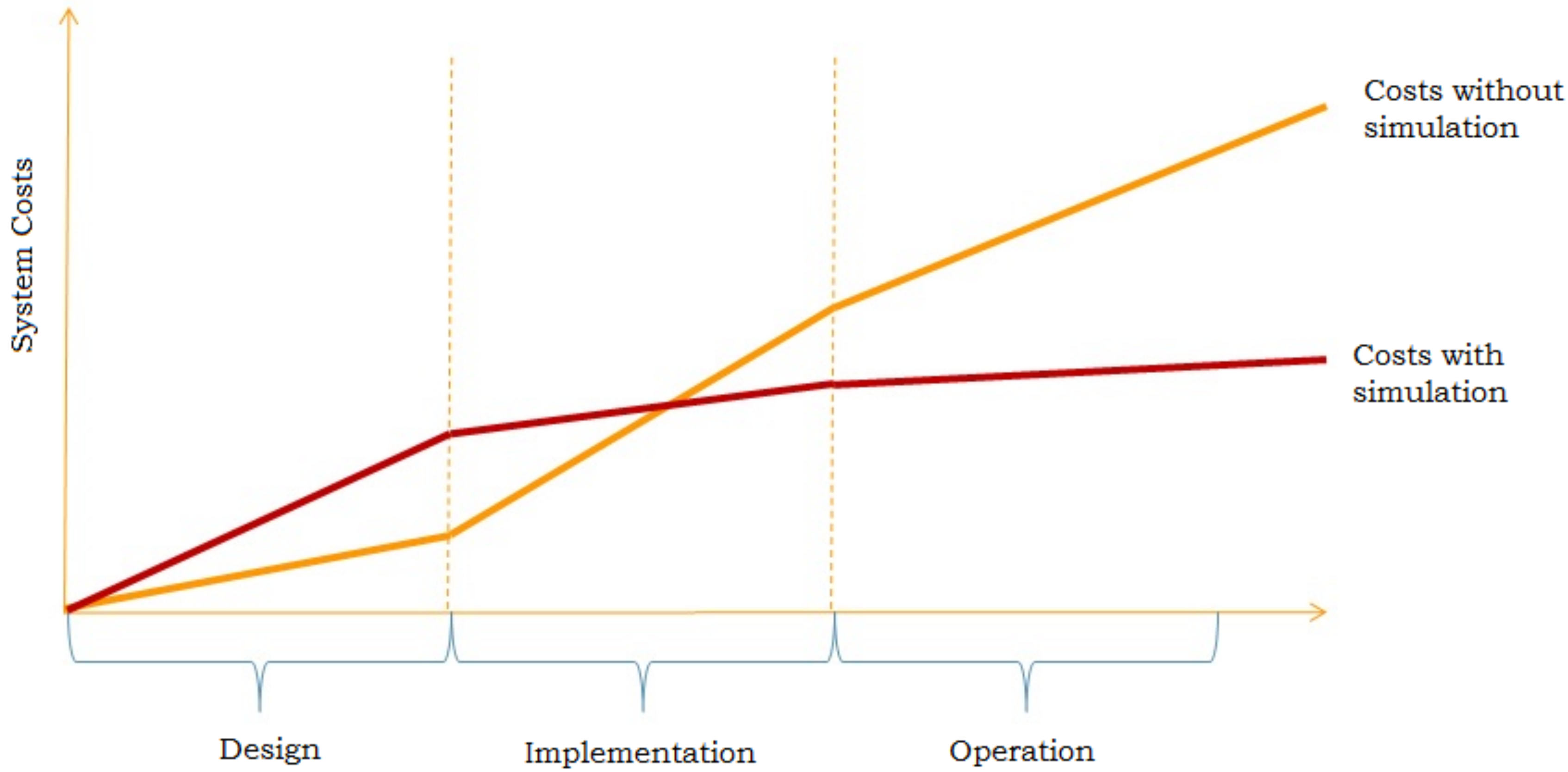
  Simulation: limited scenarios set.

  Optimization: Does not consider fluctuations in the model. Just in LP programs the sensitivity analysis.

- Advantages if they are together

  Improvement in analysis aspects and consequent optimization when possible.

Simulation and Optimization



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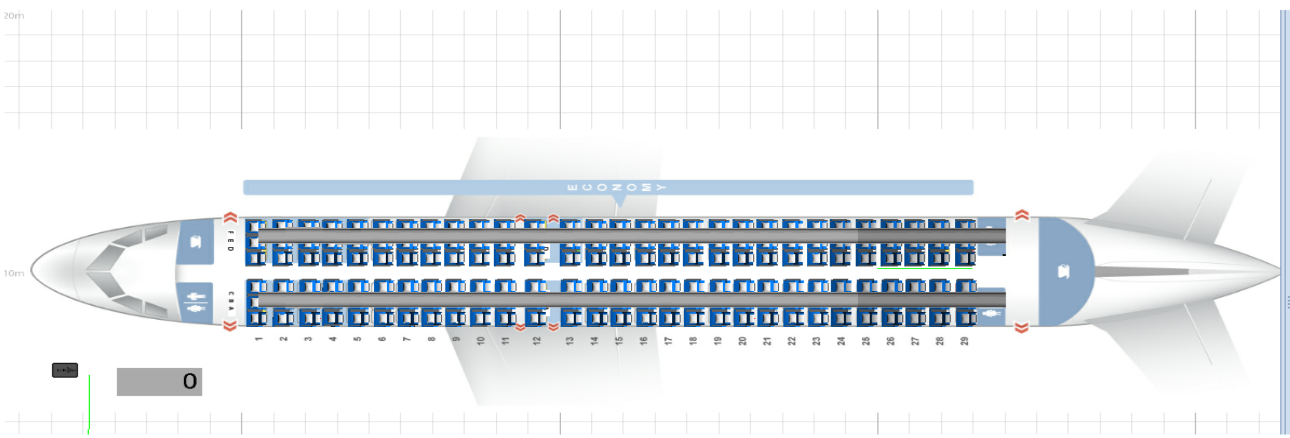
Case 1 Boarding process

The boarding process of an aircraft is part of the critical path in the turnaround process of an aircraft. This case presents a binary integer programming model to solve the problem, testing different configurations with simulation.

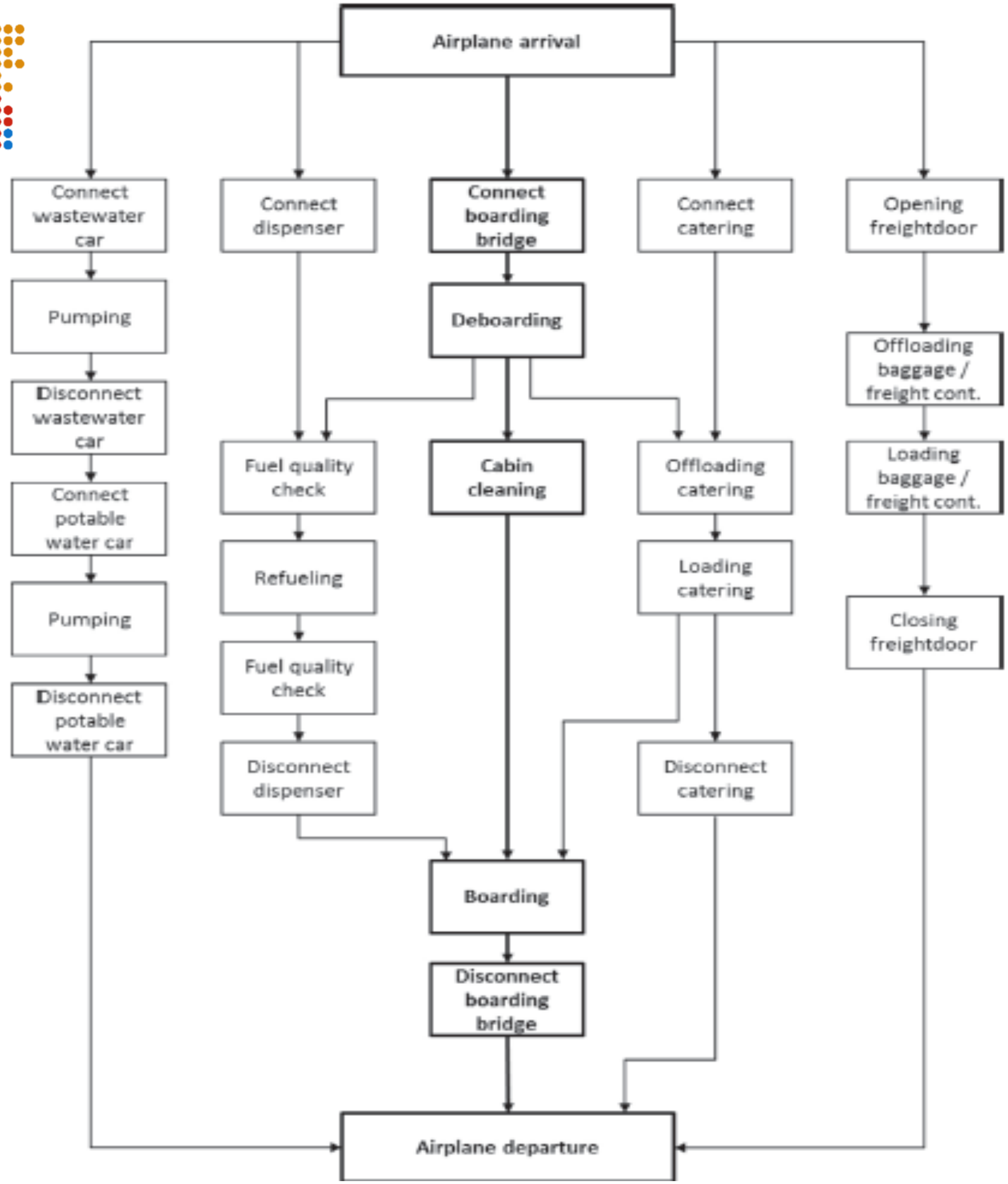
Boarding process

The turnaround time (TAT) of an aircraft is the temporary space between consecutive flights when the aircraft is in the airport.



Different times according with business

TAT of a Low Cost Carrier (LCC) is much smaller than the one for the Full Service Carrier (FSC).


Airplane arrival
Connect wastewater car
Connect dispenser
Connect boarding bridge
Connect catering
Opening freightdoor
Pumping
Deboarding
Offloading baggage / freight cont.
Disconnect wastewater car
Fuel quality check
Cabin cleaning
Offloading catering
Loading baggage / freight cont.
Connect potable water car
Refueling
Loading catering
Pumping
Fuel quality check
Closing freightdoor
Disconnect potable water car
Disconnect dispenser
Disconnect catering
Boarding
Disconnect boarding bridge
Airplane departure

Reducing TAT

In order to reduce the TAT it is necessary to reduce as much as possible the time of the steps that compose the critical path.

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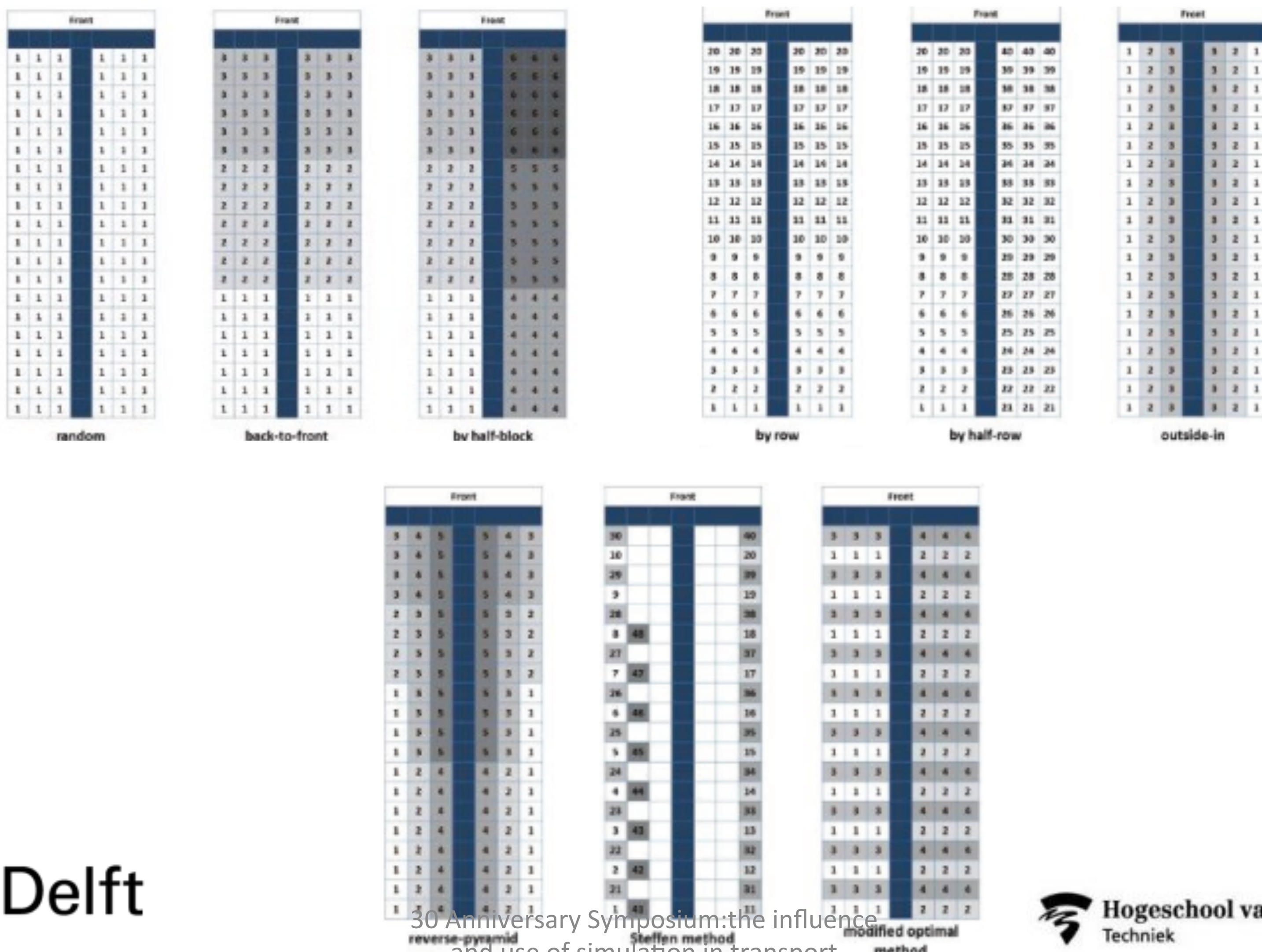
Boarding strategies



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Boarding strategies used

Strategy	Description	Advantages	Drawbacks	Usage
Random	Just one boarding group; there is no given sequence for the passengers to board, but every passenger is assigned to a particular seat	No organizational effort with calling groups; easy to understand; passengers who are traveling in a group can board together; rather fast; late passengers do not influence efficiency	Very bad worst case performance	Common (e.g., American Airlines, Lufthansa)
By group				
Back-to-front	Boarding in blocks from the back of the plane to the front	Easy to realize; passengers who are traveling in a group can board together	Congestions are concentrated on a small area of the plane; rather slow	Common (e.g., Delta Air Lines, US Airways, Lufthansa)
Outside-in/WilMA	First all window seats, then middle seats, finally aisle seats	Fast because of no seat interferences	Separation of passengers who are traveling in a group	Rare (e.g., United Airlines)
Reverse-pyramid	Mixture of *back-to-front* and *outside-in*	Fast	Rather complicated; separation of passengers who are traveling in a group possible	Rare
By block	Passengers of some consecutive rows board together; generalization of *back-to-front*; also possible *front-to-back*; possible to skip rows/blocks and board them later	Passengers who are traveling in a group can board together	Congestions are concentrated on small areas of the plane; slow if more than one block (= *random*), the more blocks, the slower	Other variants than *back-to-front* are rare
By half-block	Passengers of some consecutive rows and one side of the aisle board together	Passengers who are traveling in a group can board together	Rather slow	No usage known
By row	Passengers of one row board together	Passengers who are traveling in a group can board together	Slow; many boarding groups	No usage known
By half-row	Passengers of one row and one side of the aisle board together	Fast if rows are skipped; passengers who are traveling in a group can board together	Rather complicated	No usage known
By seat	Passengers board individually in given optimal order; number of boarding groups = number of passengers	Optimal sequence → fastest possibility	Complicated; difficult to realize/to explain to passengers; separation of passengers who are traveling in a group	Rare (e.g., Southwest Airlines)
Steffen method	Exactly two rows distance between adjacent passengers (23A, 21A, 19A, ...)	Very fast because of no seat and just few aisle interferences (maximum number of passengers can stow baggage simultaneously)	Separation of passengers who are traveling in a group; rather complicated	No usage known
Open seating	There are no assigned seats; passengers can choose any free seat when entering the plane	No organizational effort with calling groups; traveling groups can board together; passengers can avoid interferences by thoroughly choosing their seats	Often perceived as stressful by the passengers; disadvantages of first-come, first served principle; last passengers who are traveling in groups probably do not get adjacent seats	Relatively common at low-cost carriers (e.g., Southwest Airlines, Ryanair)

Methodology

The current methodology presents an integer programming (IP) model that allows to integrate the characteristics that play a role in the boarding process and also to check different configurations with the IP model using simulation, since the IP model does not have a sensitivity analysis available.

IP Model

$$\text{Minimize } Z = t_a \sum_{i=1}^{N} \sum_{j=1}^{6} \sum_{k=2}^{G} AB_{ijk} + t_a \sum_{i=1}^{N} \sum_{j=1}^{6} \sum_{k=1}^{G} AW_{ijk}$$
$$+ t_s \sum_{i=1}^{N} \sum_{k=2}^{G} (SB_{i1k} + SB_{i2k} + SB_{i5k} + SB_{i6k})$$
$$+ t_s \sum_{i=1}^{N} \sum_{k=1}^{G} (SW_{i1k} + SW_{i2k} + SW_{i5k} + SW_{i6k}) \qquad (1)$$

In the above formulation, Eq. (1) indicates that the objective is to minimize the time required to eliminate the total number of interferences among all passengers, which is equal to the sum of between-group aisle interferences, within-group aisle interferences, between-group seat interferences, and within-group seat interferences.

Constraints

Definitional contraints

$$\text{subject to: } AB_{ijk} \geq -M(1-x_{ijk}) + \alpha\left[\sum_{u=1}^{i}\sum_{v=1}^{6} x_{uvk} - 1\right],$$
$$i=1,2,\ldots,N;\ j=1,2,\ldots,6;\ k=2,3,\ldots,G \qquad (2)$$

$$AW_{ijk} \geq -M(1-x_{ijk}) + 0.5\left[\sum_{u=1}^{i}\sum_{v=1}^{6} x_{uvk} - 1\right], \quad i=1,2,\ldots,N;$$
$$j=1,2,\ldots,6; k=1,2,\ldots,G \qquad (3)$$

$$SB_{i1k} \geq -M(1-x_{i1k}) + \sum_{w=1}^{k-1} x_{i2w} + \sum_{w=1}^{k-1} x_{i3w}, \quad i=1,2,\ldots,N;\ k=2,3,\ldots,G \quad (4)$$

$$SB_{i2k} \geq -M(1-x_{i2k}) + \sum_{w=1}^{k-1} x_{i3w}, \quad i=1,2,\ldots,N;\ k=2,3,\ldots,G \qquad (5)$$

$$SB_{i5k} \geq -M(1-x_{i5k}) + \sum_{w=1}^{k-1} x_{i4w}, \quad i=1,2,\ldots,N;\ k=2,3,\ldots,G \qquad (6)$$

$$SB_{i6k} \geq -M(1-x_{i6k}) \sum_{w=1}^{k-1} x_{i4w} + \sum_{w=1}^{k-1} x_{i5w}, \quad i=1,2,\ldots,N;\ k=2,3,\ldots,G \quad (7)$$

$$SW_{i1k} \geq 0.5[-M(1-x_{i1k}) + x_{i2k} + x_{i3k}], \quad i=1,2,\ldots,N;\ k=1,2,\ldots,G \qquad (8)$$

$$SW_{i2k} \geq 0.5[-M(1-x_{i2k}) + x_{i3k}], \quad i=1,2,\ldots,N;\ k=1,2,\ldots,G \qquad (9)$$

$$SW_{i5k} \geq 0.5[-M(1-x_{i5k}) + x_{i4k}], \quad i=1,2,\ldots,N;\ k=1,2,\ldots,G \qquad (10)$$

$$SW_{i6k} \geq 0.5[-M(1-x_{i6k}) + x_{i4k} + x_{i5k}], \quad i=1,2,\ldots,N;\ k=1,2,\ldots,G \qquad (11)$$

Constraints 2

$$\sum_{k=1}^{G} x_{ijk} \leq 1, \quad i=1,2,\ldots,N;\ j=1,2,\ldots,6 \tag{12}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{6} x_{ijk} \geq L, \quad k=1,2,\ldots,G \tag{13}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{6} x_{ijk} \leq U, \quad k=1,2,\ldots,G \tag{14}$$

$$\sum_{i=1}^{N}\sum_{i=1}^{6}\sum_{k=1}^{G} x_{ijk} = \lfloor \beta(6N) \rfloor \tag{15}$$

$$x_{ijk} = 0 \text{ or } 1, \quad i=1,2,\ldots,N;\ j=1,2,\ldots,6;\ k=1,2,\ldots,G \tag{16}$$

The purpose of Eq. (12) is to ensure that each passenger will be assigned to no more than one boarding group, Eqs. (13) and (14) are imposed so that the size of each boarding group will fall within the desirable range, and Eq. (15) states that the total number of seats taken is equal to the total number of passengers to board the plane. Lastly, Eq. (16) indicates that all decision variables are binary.

Simulation results

Results for an A320 economy section 138 passengers

Speed 0.8 m/s	AVG	MIN	MAX	HALF WIDTH
Rear to Front OUT_IN	9.2928	9.0434	9.5242	0.0317
Rotating Zone OUT-IN	9.3495	9.1	9.5809	0.0317
Block Boarding (Ordered)	9.2928	9.0434	9.5242	0.0317
Block Boarding (Random)	9.753	9.5165	9.9892	0.0309
WiLMA (Outside-in)	9.2928	9.0434	9.5242	0.0317
Reverse Pyramid	9.2928	9.0434	9.5242	0.0317
Random assigned	9.9674	9.7319	10.2313	0.0318
Steffen	9.2798	9.0303	9.5112	0.0317
Random selected 1	9.4661	9.2167	9.6976	0.0317
random selected 2	9.3387	9.0893	9.5702	0.0317
random selected 3	9.3786	9.1227	9.621	0.0321

Ranking based on max

Speed 0.8 m/s	AVG	MIN	MAX	HALF WIDTH
Steffen	9.2798	9.0303	9.5112	0.0317
Rear to Front OUT_IN	9.2928	9.0434	9.5242	0.0317
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Random- selected 1	9.4661	9.2167	9.6976	0.0317
Block Boarding (Random)	9.753	9.5165	9.9892	0.0309
Random assigned	9.9674	9.7319	10.2313	0.0318

Ranking based on min

Speed 0.8 m/s	AVG	MIN	MAX	HALF WIDTH
Steffen	9.2798	9.0303	9.5112	0.0317
Rear to Front OUT_IN	9.2928	9.0434	9.5242	0.0317
Block Boarding (Ordered)	9.2928	9.0434	9.5242	0.0317
WiLMA (Outside-in)	9.2928	9.0434	9.5242	0.0317
Reverse Pyramid	9.2928	9.0434	9.5242	0.0317
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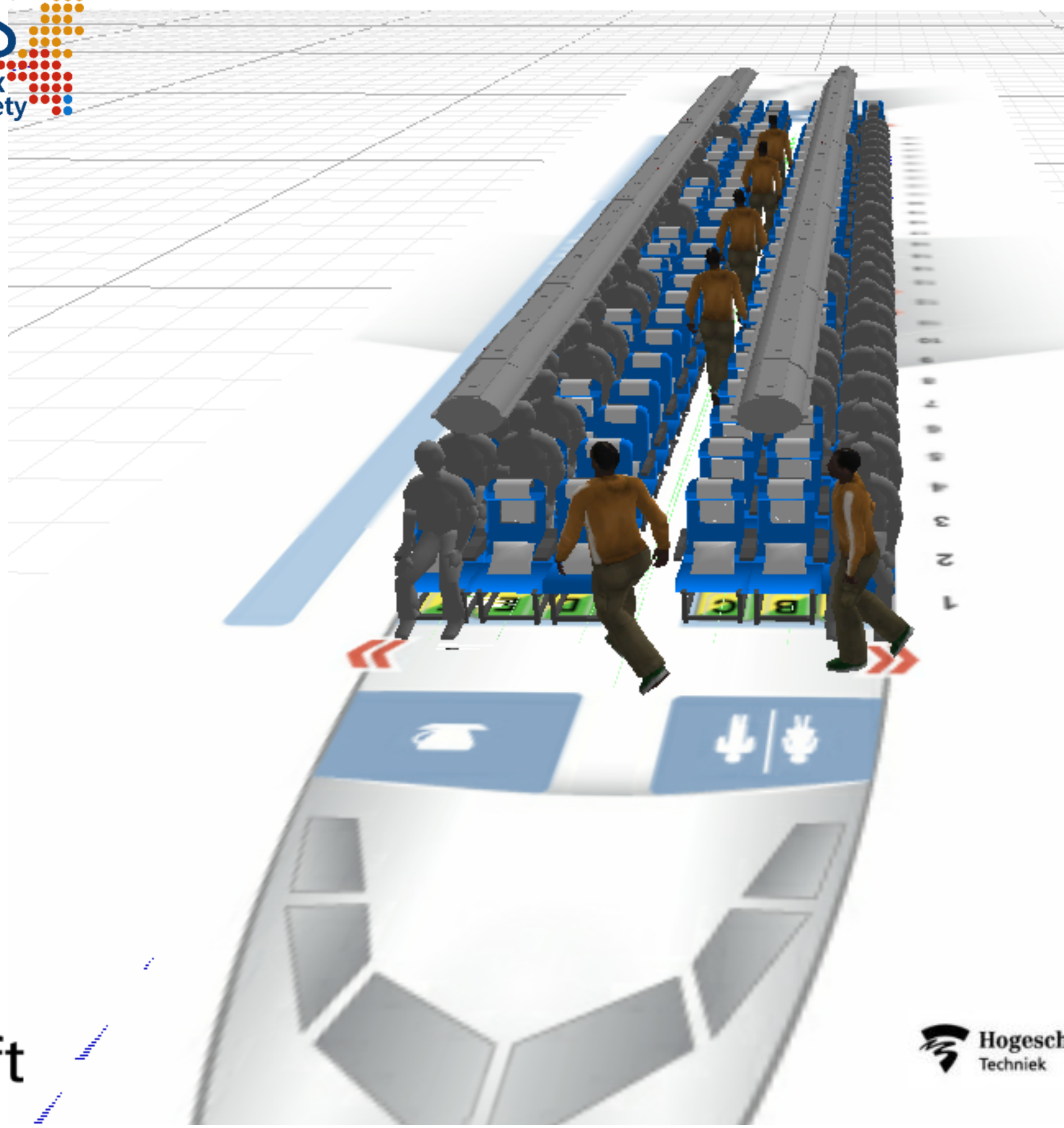

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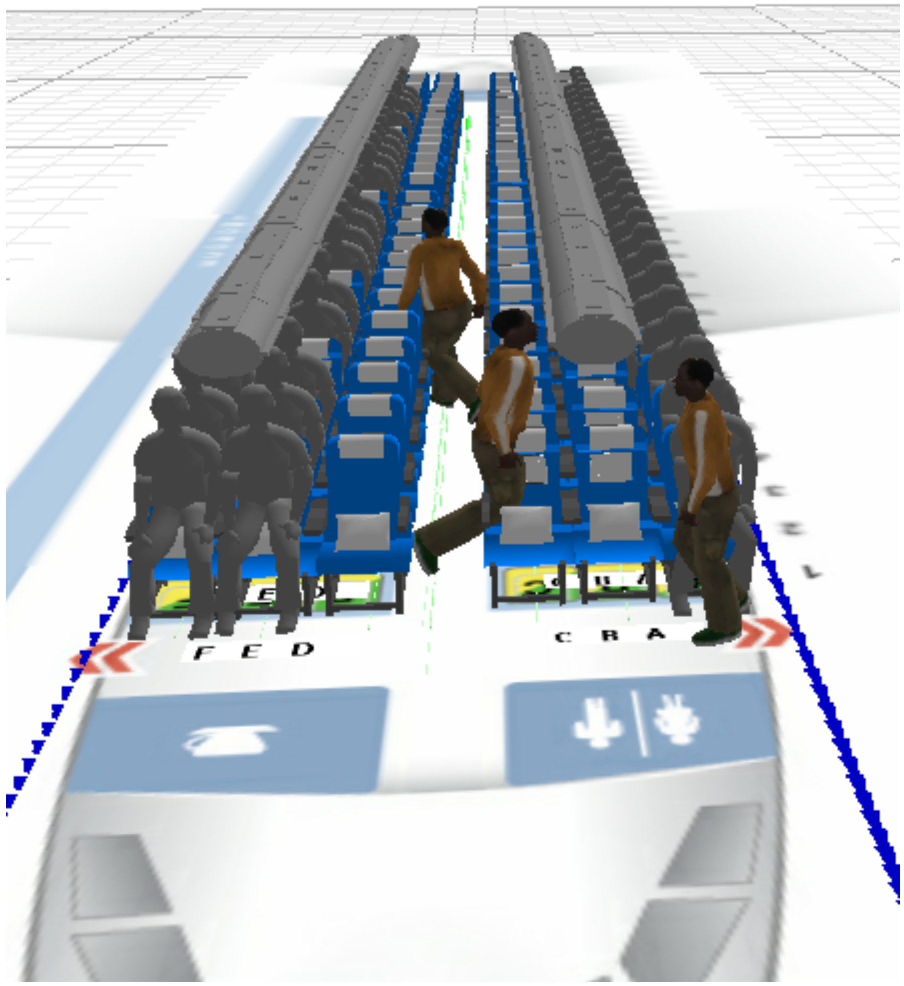

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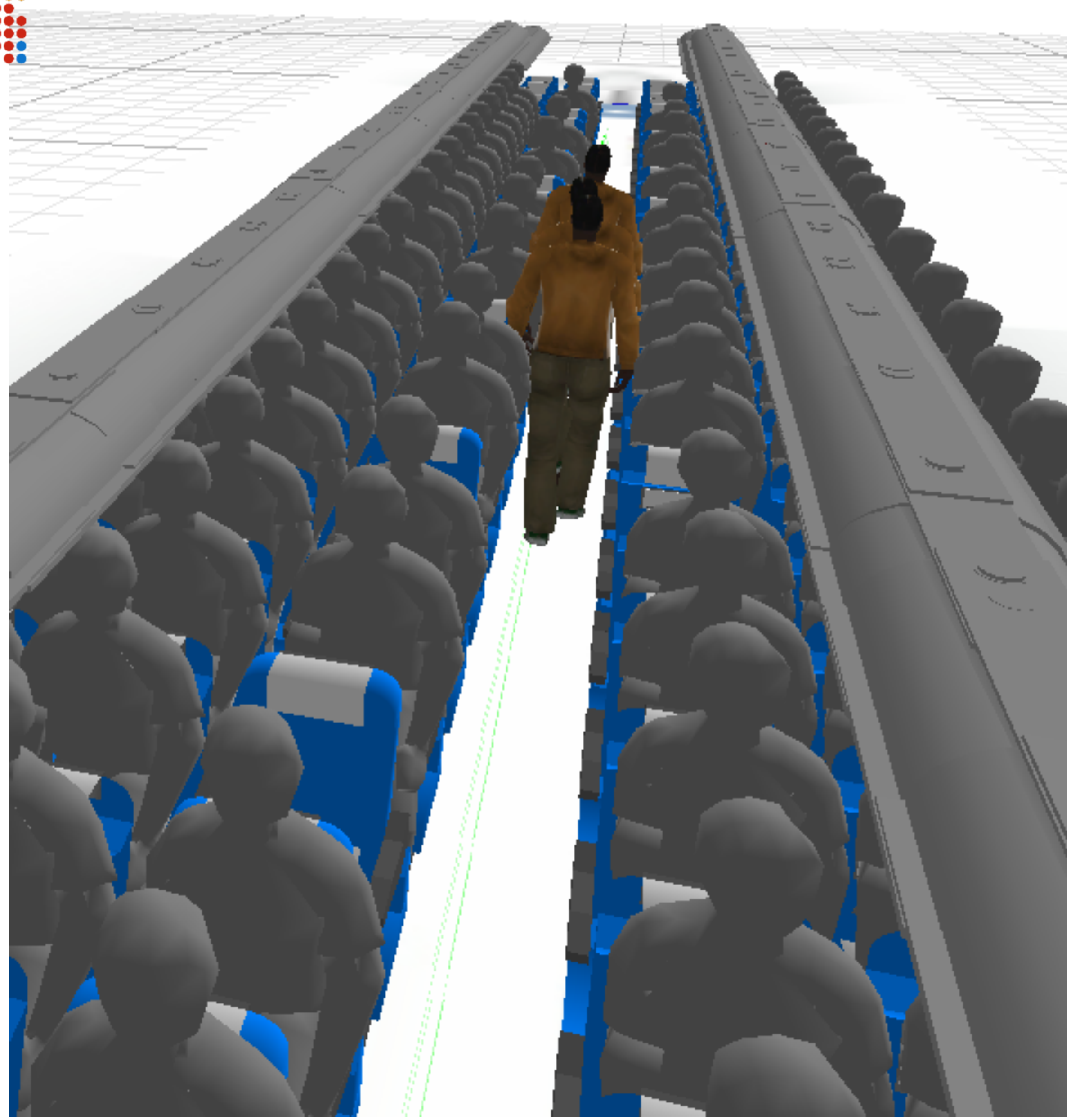

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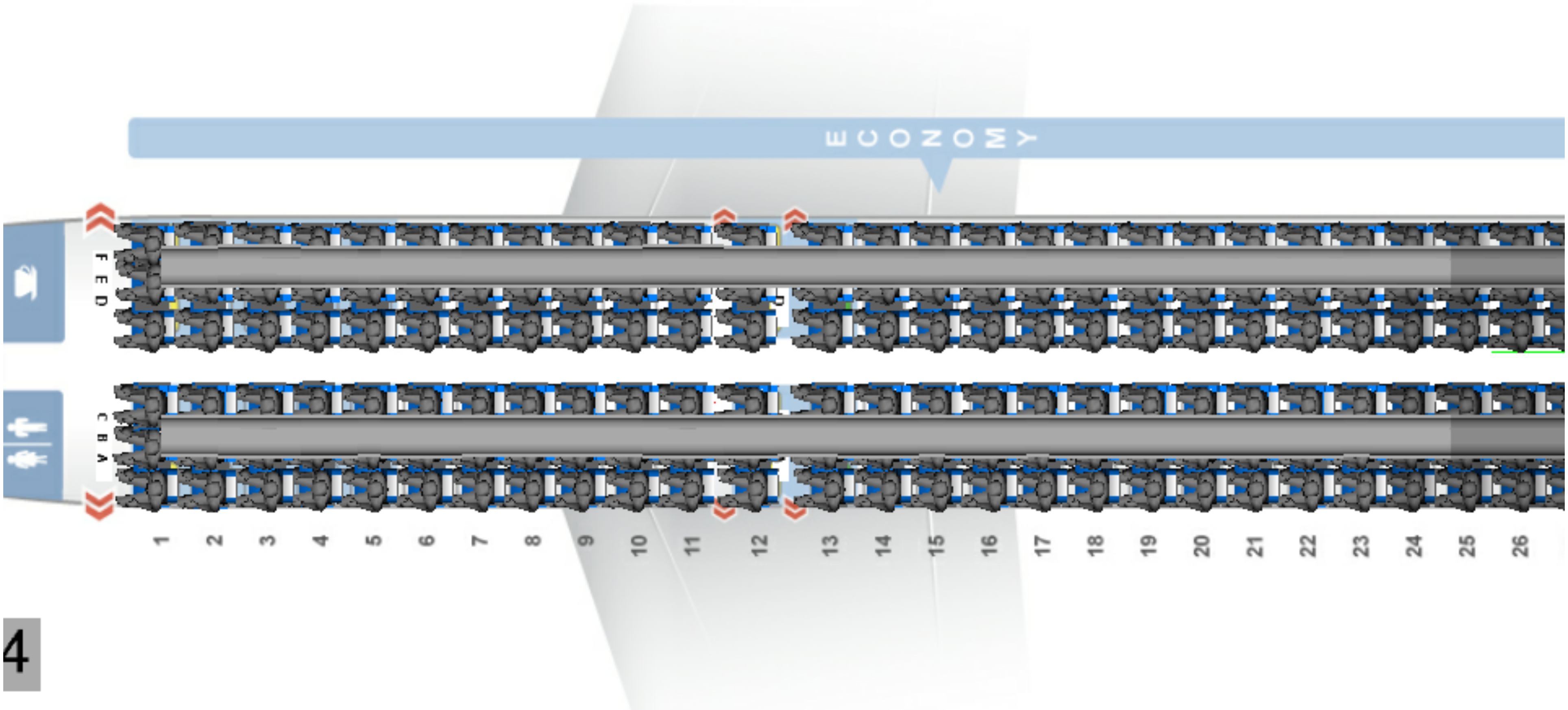

Conclusions

Based on this research we found a good boarding scheme but more experiments are needed, for different aircraft models and to compare the IP program with other mathematical models.

Case 2 Mexico city mobility

- The activities of managing and planning services in a context of cities entails a lot of work and participation of experts in different areas.
- Such is the case of transport that currently represents a challenge for researchers from different areas.
- There are three measures used for transportation analysis: traffic, mobility and accessibility.

Introduction

- Mexico City is divided by sectors; each sector has its own local responsibilities of management.
- A research about certain aspects of Mexico City should be conducted at different levels.
  - ✓ Considering the complete city, at macro level.
  - ✓ Second level the relationship between the different political sectors.
  - ✓ Third level analyze each sector individually.

Map of Mexico City with sectors

Traffic congestion

- Last year Mexico City ranked the highest congestion level on the road network, causing more than 90% extra travel time for citizens during busy hours.
- The aim of this study is to carry out a diagnosis about the public transport network in Mexico City for proposing a pertinent theoretical tool to optimize its operations on a daily basis.

Socio-economics KPI´s of Mexico City

Periods of high growth without effective planning and increasing motorization, have pushed Mexican cities towards a "3D" urban growth model: distant, disperse, and disconnected.

The 3D model is a direct result of national policies subsidizing housing projects in the outskirts of urban agglomerations, managing urban and rural land poorly, and prioritizing car-oriented solutions for transportation.

The alternative is a 3C urban growth model: Compact, connected and coordinated.

Administrative organization	The metropolitan area of Mexico is composed of 16 Delegations in the Federal District, 58 municipalities in State of Mexico, and 1 Municipality in State of Hidalgo.
Population (2008)	Federal District: 8.8 million Metropolitan area (Federal District and State of Mexico): 19.2 million
Area (2010)	Federal District: 1,487 km2 Metropolitan area: 7,180 km2 (40.1% of which is urbanized)
Population density (2010)	Federal District: 5,958 people/km2 Metropolitan area: 6,671 people/km2
Annual population growth rate (2005 - 2010)	Federal District: 1.49% Metropolitan area: 3.96%
GDP and growth (2011)	163.6 billion USD (17% of the national GDP, Federal District only) Annual GDP growth (2008-2011): 4%
Unemployment rate (2011)	6.5%

Mobility in Mexico City

Total trips per day (2007)	48.8 million (Metropolitan area) and 32.0 million (Federal District)
Daily trips per person (2007)	2.5 (Metropolitan area) and 3.6 (Federal District)

Trips and modal share in the Federal District (2007)

Mode	Trips	% Total	% Public transport
Non motorized	8,600,000	26.9%	
Private vehicles	4,800,000	15.0%	
Microbuses	9,448,800	29.5%	50.8%
Metro	4,984,800	15.6%	26.8%
Autobuses	1,878,600	5.9%	10.1%
Taxis	1,041,600	3.3%	5.6%
Metrobus	762,600	2.4%	4.1%
Trolley (RTP)	204,600	0.6%	1.1%
Suburban train	167,400	0.5%	0.9%
Light train	111,600	0.3%	0.6%
Total	32,000,000	100.0%	58.1%

Road network (2007)	10,200 km (91% local roads)

Total vehicles (Federal District, 2001)

Cars	4,460,386
Taxis	225,302
Motorcycle	11,920
Microbuses	20,459
Buses	8,240
Combis	3,519
Metrobus – articulated buses	322
Metrobus – regular buses	54
Metrobus – biarticulated buses	27
Totals	4,730,228

Road safety (2010)

Total number of accidents	14,729
Number of deaths	1,026
Involved vehicle in deaths	81.0% Car 5.6% Truck 3.5% Microbus
Involved victim in deaths	52.0% Pedestrian 20.0% Car driver 14.0% Motorcycle driver

Emissions (contribution by vehicle type) (2006)

Pollutant	*Cars*	*Taxis*	*Microbuses*	*Buses*	*Motorcycles*	*Trucks*
CO_2	58.0%	6.2%	13.2%	1.9%	6.0%	14.7%
NO_x	46.2%	6.9%	11.4%	10.2%	1.0%	24.3%
$PM_{2.5}$	14.2%	2.4%	1.6%	25.2%	1.5%	55.1%

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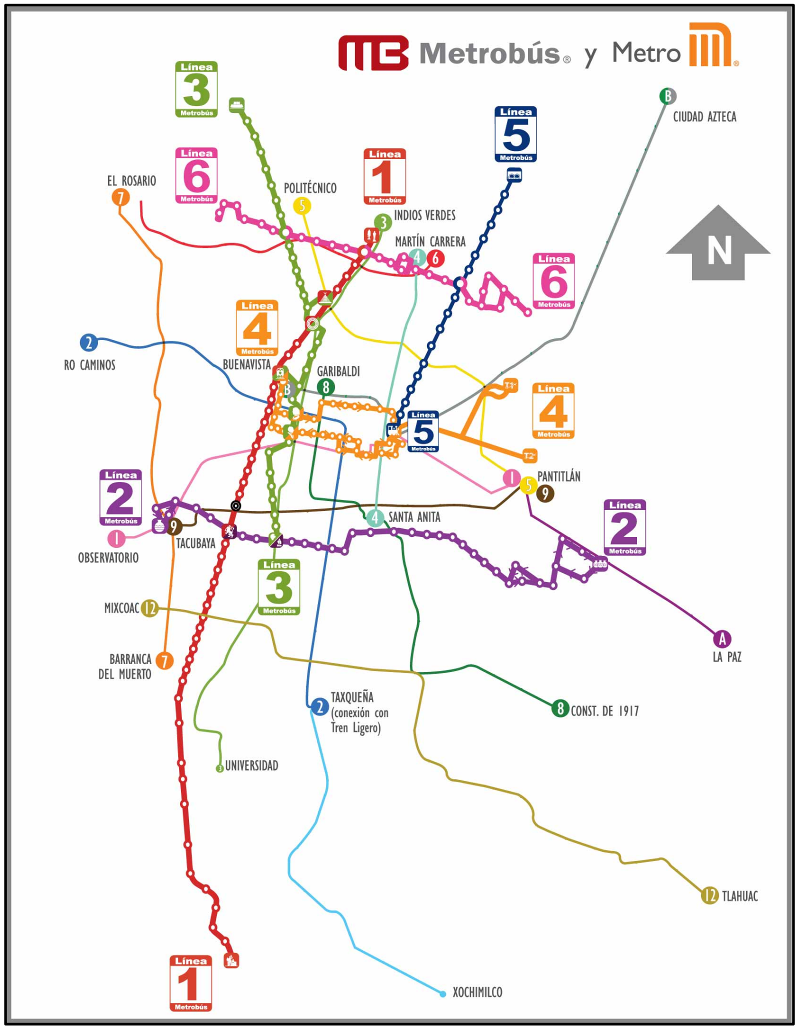
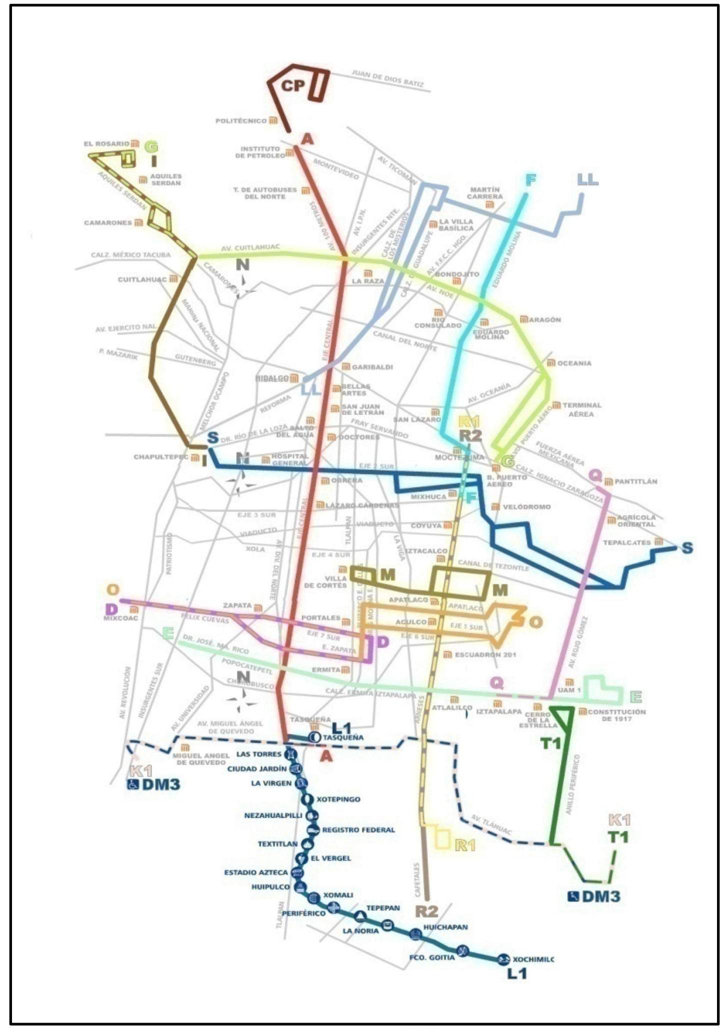
The public transport network in Mexico City context





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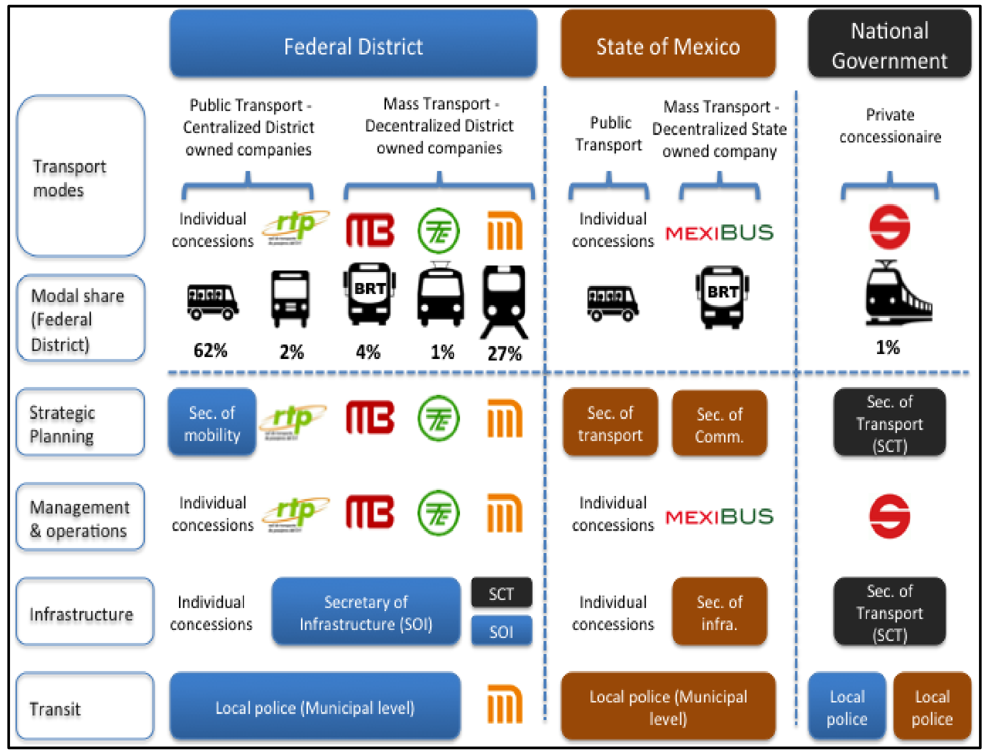
Management of Public Transport

- The management of the public transport in Mexico City is fragmented and this makes it difficult to establish some planning policies for its improvement



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Complex networks

The public transport networks in Mexico City are considered complex and both vulnerability and resilience are important factors to take into account. As Reggiani (2015) states, the following questions need to be answered:

- Is a complex network a necessary condition for the emergence or presence of transport resilience and vulnerability?

  "the term 'complexity' embeds both the assemblage of different units in a system and their intertwined dynamics.

  Furthermore, connectivity is one of the essential elements that characterize complex networks.

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Complex Networks

- Several indicators of resilience and vulnerability co-exist; are these differences related to specific fields of transportation research?

  Resilience and vulnerability conditions associated with such hubs can then impact on the resilience/ vulnerability of the whole network.

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Complex Networks

Can connectivity or accessibility be considered as a unifying framework for understanding and interpreting – in the transport literature – the concepts of resilience and vulnerability?

For optimizing urban mobility in Mexico City, we propose to carry out a network analysis based on traffic, mobility and accessibility aspects to develop a simulation model.

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An example of disconnected network

In Buenavista - an area of Mexico City where three modes of transport converge – travellers must walk up to 1.5 km to transfer from one mode to another. Close to 150,000 users use this disconnected transport hub every day with significant costs for users as well as for operators.

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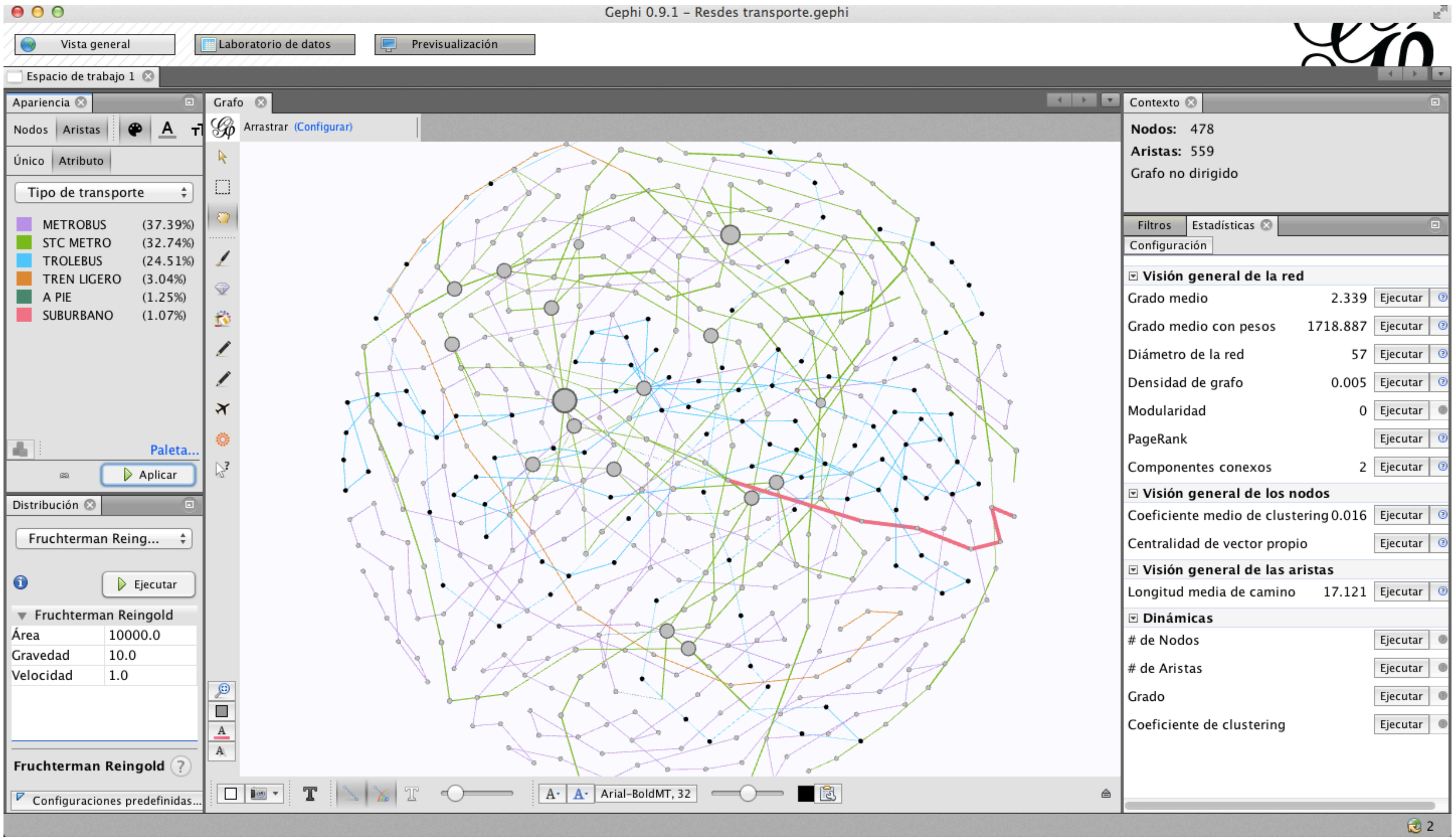
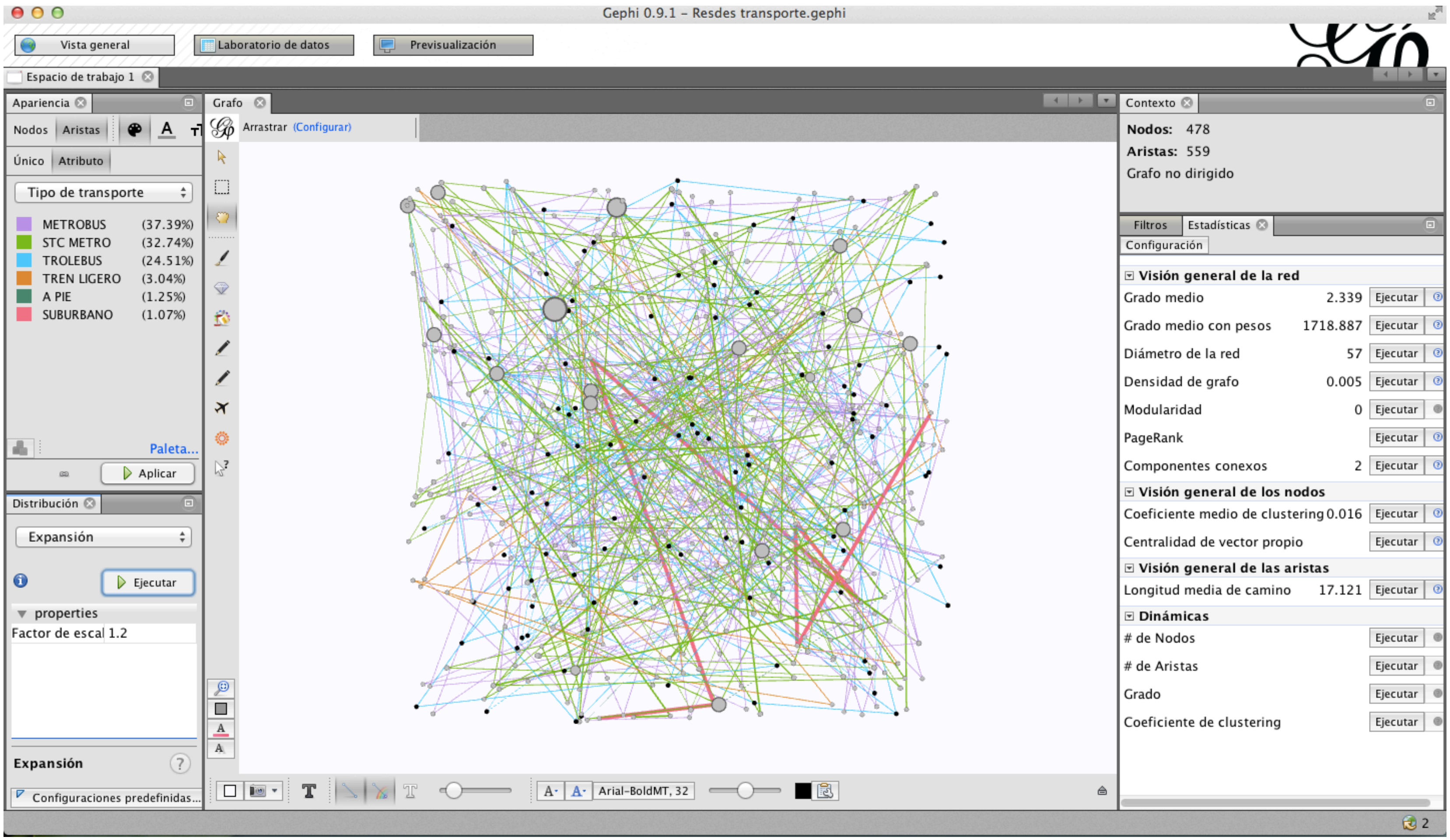
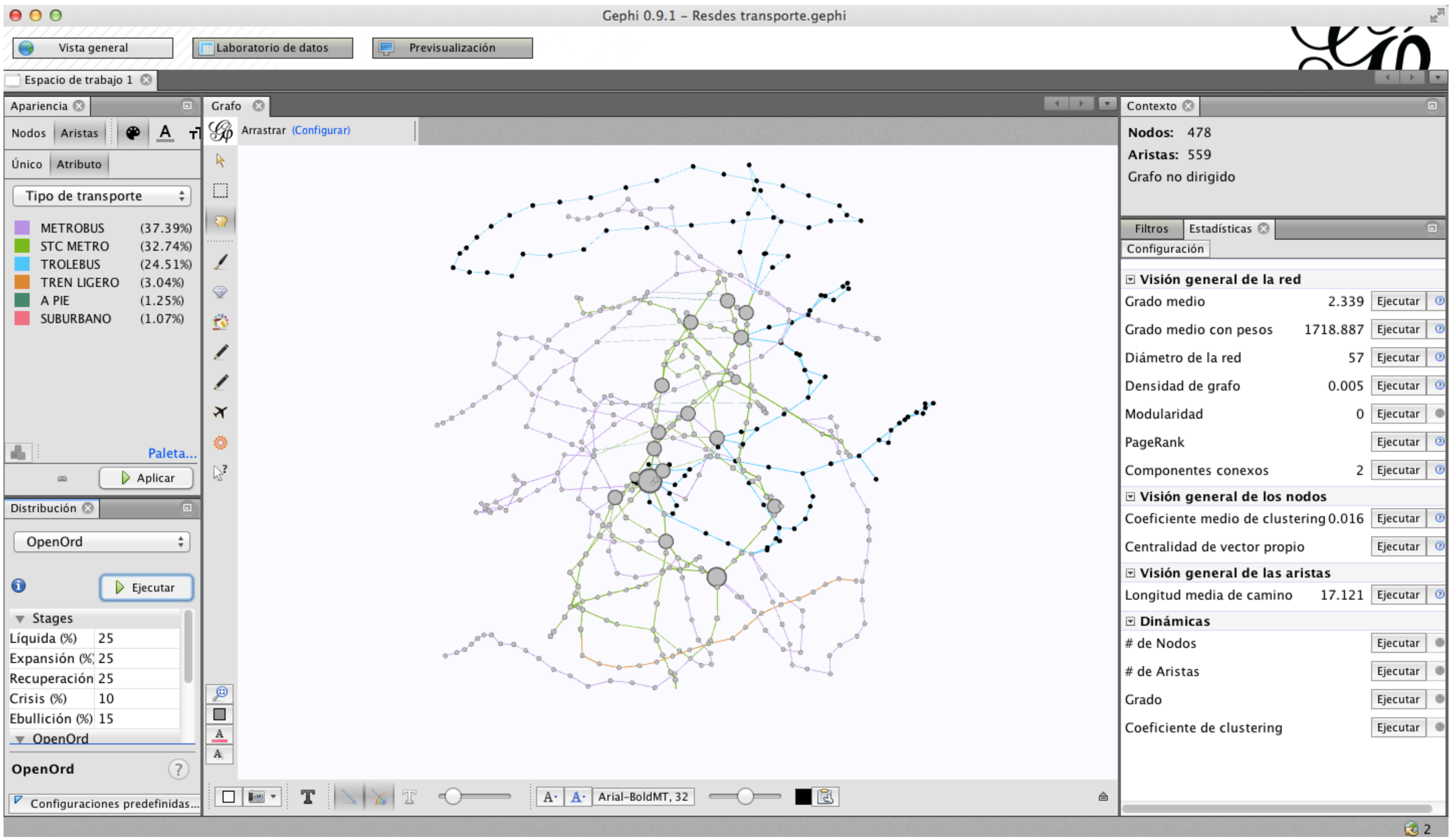
Suburban train



Different modes

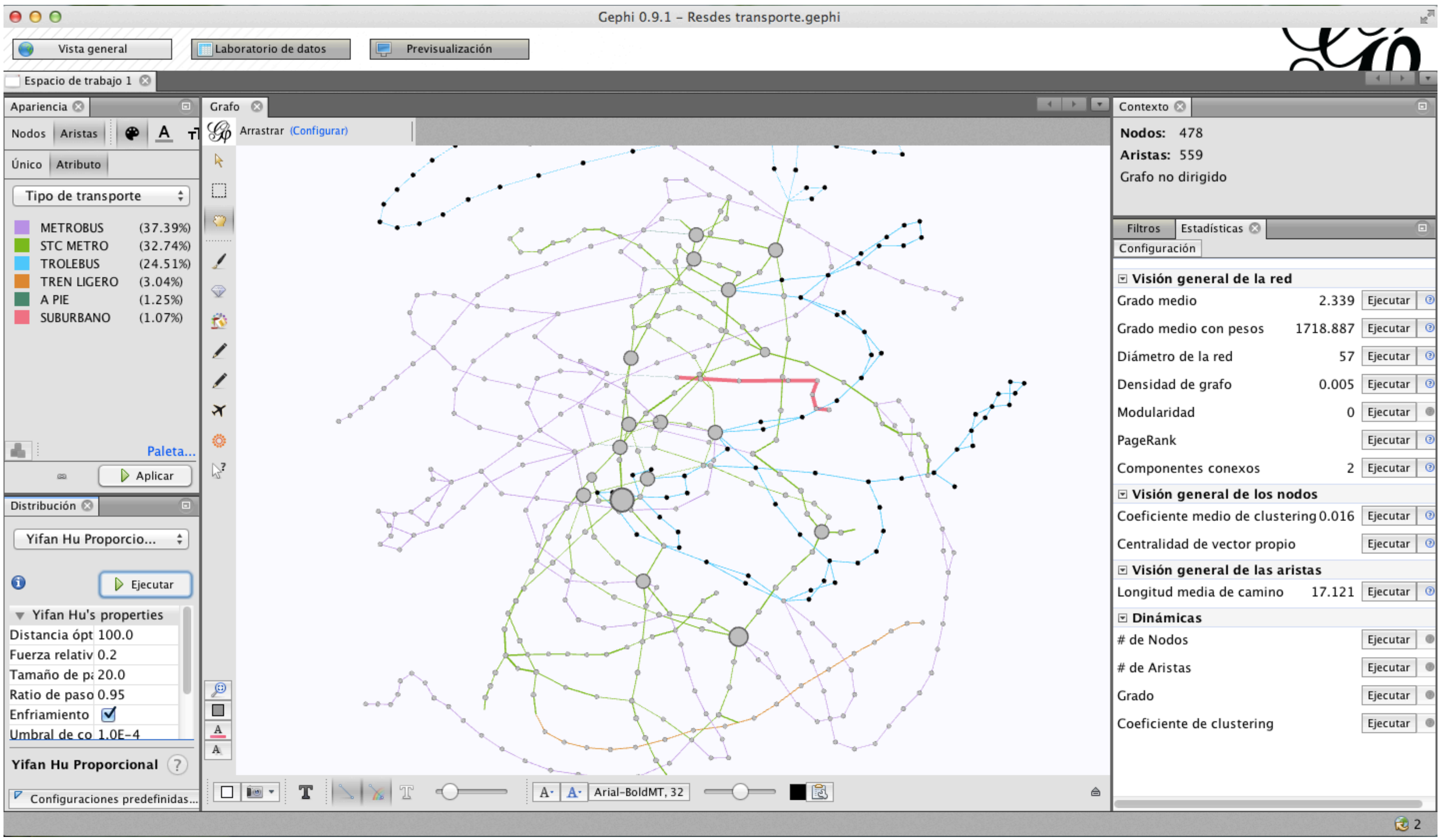


Centroids

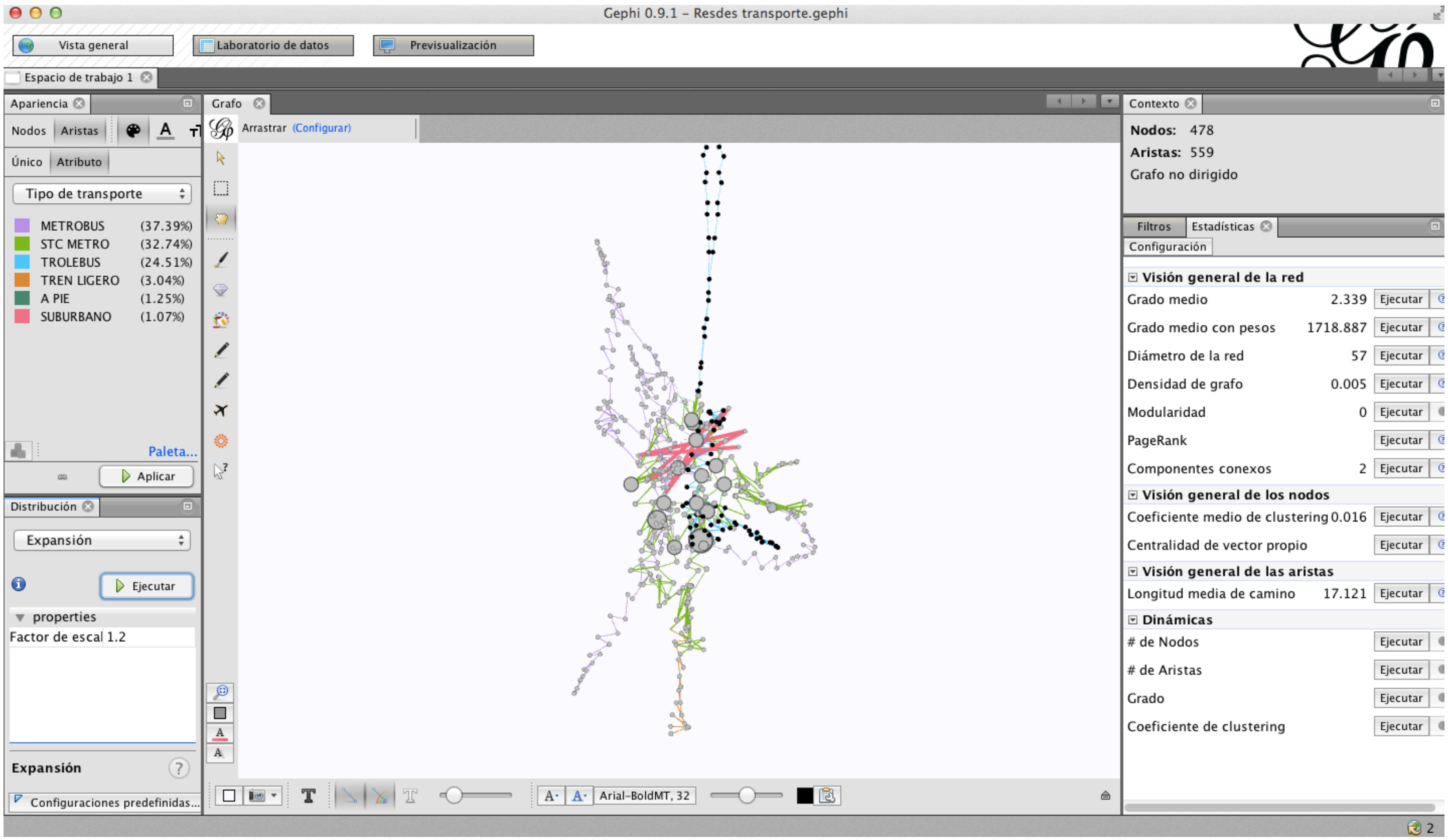


Gephi 0.9.1 – Resdes transporte.gephi
Vista general
Laboratorio de datos
Previsualización
Espacio de trabajo 1
Apariencia
Nodos
Aristas
Único
Atributo
Tipo de transporte
METROBUS (37.39%)
STC METRO (32.74%)
TROLEBUS (24.51%)
TREN LIGERO (3.04%)
A PIE (1.25%)
SUBURBANO (1.07%)
Paleta...
Aplicar
Distribución
OpenOrd
Ejecutar
Stages
Líquida (%) 25
Expansión (%) 25
Recuperación 25
Crisis (%) 10
Ebullición (%) 15
OpenOrd
Configuraciones predefinidas...
Grafo
Arrastrar (Configurar)
Arial-BoldMT, 32
Contexto
Nodos: 478
Aristas: 559
Grafo no dirigido
Filtros
Estadísticas
Configuración
Visión general de la red
Grado medio 2.339
Grado medio con pesos 1718.887
Diámetro de la red 57
Densidad de grafo 0.005
Modularidad 0
PageRank
Componentes conexos 2
Visión general de los nodos
Coeficiente medio de clustering 0.016
Centralidad de vector propio
Visión general de las aristas
Longitud media de camino 17.121
Dinámicas
de Nodos
de Aristas
Grado
Coeficiente de clustering

Disconnected nodes



General view



Conclusions

- Recent studies that have been made on mobility in Mexico City have a transportation management approach, but they have not used a systemic approach and made use of quantitative tools such as simulation and optimization.
- As we can see the analysis proposed is innovative because it considers the transport network as a complex network that has as an important issue with the disconnection.
- At a macro level, connectivity analysis is verified through an optimization algorithm, then the simulation is used to design simulation scenarios and search for feasible solutions.
- For future research some results in the macro level will be available, a mezzo and micro level analysis will be developed.

THANK YOUU!!