Disruptive technologies and supply chain design under the Physical Internet paradigm

Prof. Dr. Jairo R. Montoya-Torres

Prof. Dr. William J. Guerrero

Dr. David L. Cortés-Murcia

MSc. Oscar Ariztegui

Dr. Rafael D. Tordecilla

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Universidad de La Sabana

The ePIcenter Project

ePICenter

Enhanced Physical Internet-Compatible Earth-frieNdly freight Transportation answER

Key information:

42 months

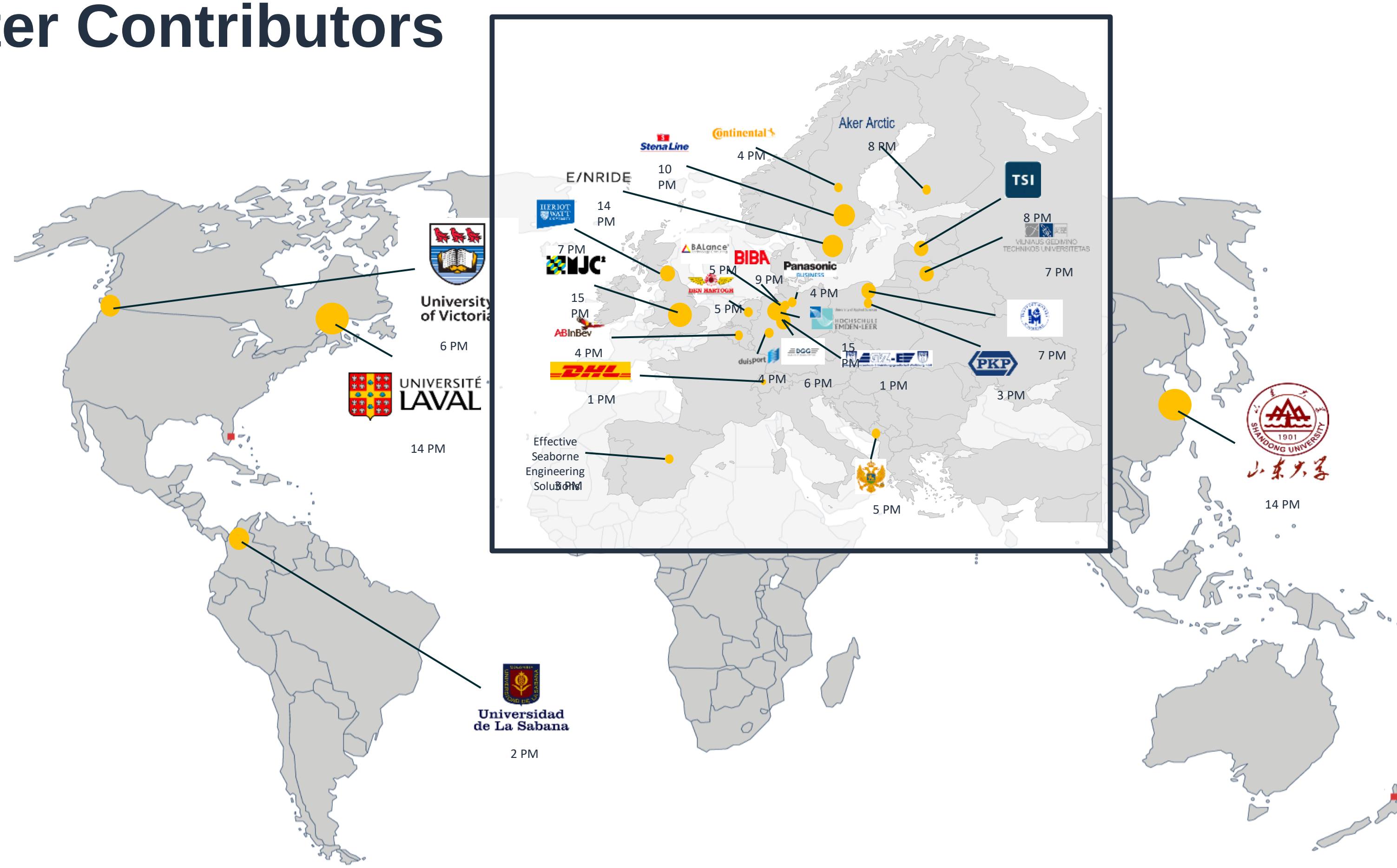
Start date: June 1, 2020

Leader: Port of Antwerp, Belgium

36 partners, 3 continents

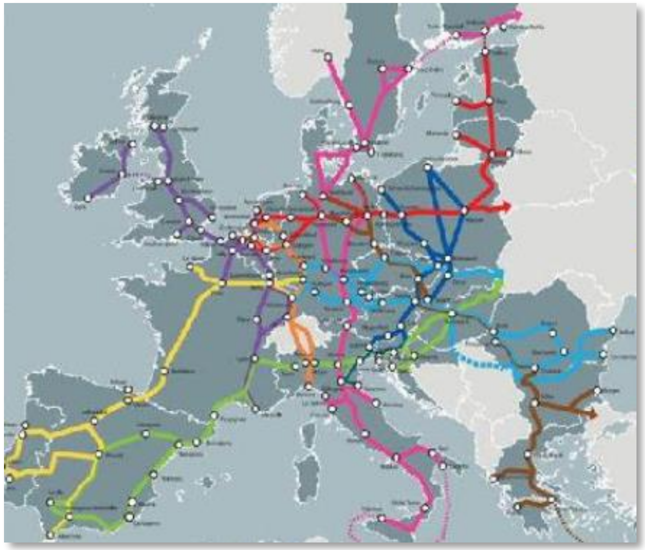
2 China, 4 North Am. (1 USA, 3 CA), **1 LATAM**, 29 Europe

ePIcenter Contributors



General objective

- To create an interoperable cloud-based ecosystem of user-friendly extensible Artificial Intelligence-based logistics software solutions and supporting methodologies.
- This objective will yield solutions that are:
  - Agile.
  - Innovative.
  - Sustainable.
  - Resilient.
  - Powered by the actors' collaboration.



General objective

- ePIcenter will:
  - Speed up the path to a Physical Internet.
  - Benefit peripheral regions and landlocked developing countries.
  - Reduce fuel usage and corresponding emissions.
  - Lead to a greater utilization of greener modes of transport reducing long distance movements by trucks.
  - Ensure a smoother profile of arrivals at ports which will reduce congestion and waiting/turnaround times.

Physical Internet (PI)

- Treiblmeier (2019) defines the PI as "a comprehensive and measurable supply chain framework which is based on a network of physical components. These components are standardized as well as optimized and exchange information to improve the effectiveness, efficiency, and sustainability of supply chain management operations."

Montreuil, B., 2011. Toward a Physical Internet: meeting the global logistics sustainability grand challenge. *Logistics Research* 3, 2, 71–87.

Montreuil, B., et al., 2013. Physical Internet foundations. In *Service orientation in holonic and multi agent manufacturing and robotics*. Springer, pp. 151–166.

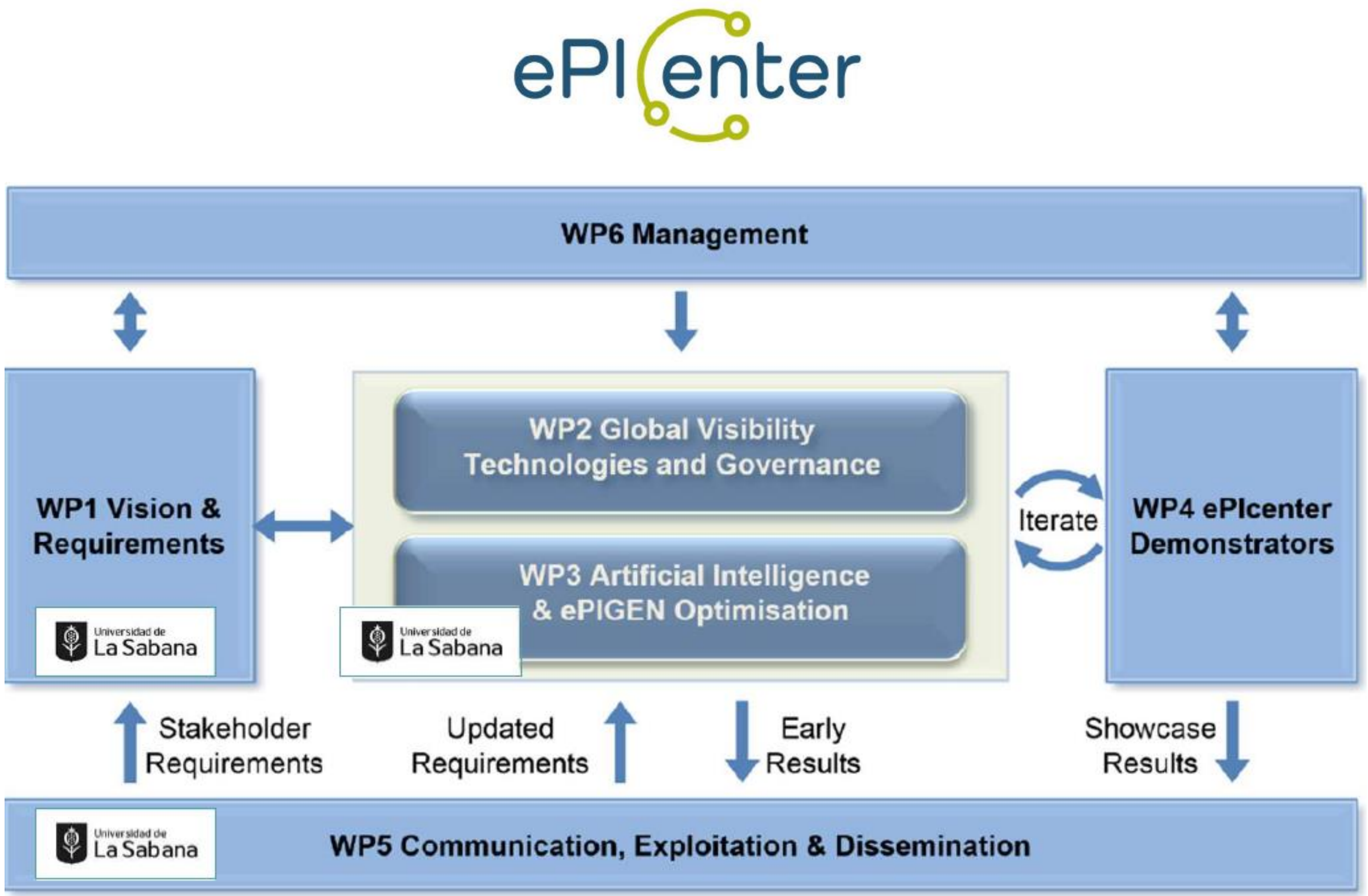
Treiblmaier, H., 2019. Combining Blockchain technology and the Physical Internet to achieve triple bottom line sustainability: a comprehensive research agenda for modern logistics and supply chain management. *Logistics*, 3, 10, 1-13.

Treiblmaier, H., et al., 2020. The Physical Internet as a new supply chain paradigm: a systematic literature review and a comprehensive framework. *The International Journal of Logistics Management,* 31, 2, 239–287.

Physical Internet (PI)

- The PI has the following foundations (Montreuil et al., 2013):
  - Efficiency and sustainability.
  - Universal interconnectivity.
  - Encapsulation.
  - Standard smart interfaces.
  - Standard coordination protocols.
  - Logistics web enabler.
  - Open global logistics system.
  - Innovation-driven PI.

Work packages



WP1. Vision, opportunities and requirements

- Technology scan and state-of-the-art refresh.

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Supply Chain Management, Game-Changing Technologies, and Physical Internet: A Systematic Meta-Review of Literature

DAVID L. CORTÉS-MURCIA, WILLIAM J. GUERRERO, AND JAIRO R. MONTOYA-TORRES
Research Group in Logistics Systems, School of Engineering, Universidad de la Sabana, Chía, Cundinamarca 250001, Colombia
Corresponding author: David L. Cortés-Murcia (david.cortes@chiper.co)

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ABSTRACT To improve the effectiveness and the sustainability of logistics, the Physical Internet paradigm proposes disruptive solutions. This implies developing an ecosystem of tech-based logistics solutions and supporting methodologies that enable all players in global trade to cooperate. The purpose of this paper is to investigate systematic literature review (SLR) studies to gain detailed insight into how innovative transport technologies, and digitalization initiatives around the Physical Internet development impact supply chains. This paper presents the results of a tertiary study that systematically identified more than twelve thousand articles and selects to review 74 secondary studies on the application of disruptive technologies and the Physical Internet initiative on supply chains from a management perspective. This is complementary to previous reviews, since no one provides a comprehensive and consolidated approach towards the relationship of these three fields. The five-stage systematic review process proposed by Denyer and Tranfield (2009) is followed. As a result, we identify the key activities, knowledge areas and strategies in the supply chain field where the Physical Internet and disruptive technologies interact and are game-changing. Also, we present a conceptual framework that summarises the relationships that exist between relevant disruptive technologies, the physical internet topics, and supply chain key activities. The framework is helpful for researchers and practitioners to find potential technologies to invest in, to assess the potential effects on companies of their implementation, and to support strategic decision-making. The paper concludes with an outlook on future research opportunities from operational, tactical, and strategic perspectives.

INDEX TERMS Disruptive technologies, logistics, physical internet, supply chain management, systematic literature review, tertiary study, transport.

I. INTRODUCTION

Since the Kyoto Protocol, governments and policymakers around the world have tried to deal with the increasing environmental challenges resulting from the climate crisis, pollution, and deforestation that endanger the sustainability of the planet [1]. However, in recent years, mankind proved that reducing the negative impact of supply chain (SC) operations on society and the environment is a difficult task [2]. Additionally, the United Nations proposed an agenda for 2030 composed of a set of 17 Sustainable Development Goals (SDG), which includes efforts to "make cities and human settlements inclusive, safe, resilient and sustainable" (SDG 11), "ensure sustainable consumption and production patterns" (SDG 12), and "take urgent action to combat climate change and its impacts" (SDG 13).

Transport is a key driver in many economic activities that account for about 24% of world CO_2 emissions [3]. Moreover, the accelerating technological changes and the establishment of new players in international trade force local, regional, and global transportation to change. Due to this, there is an increasing interest in developing research around topics such as reverse logistics, closed-loop logistics, green logistics and environmental logistics [4]. Also, there are projects with international cooperation and with multidisciplinary research groups from universities and companies

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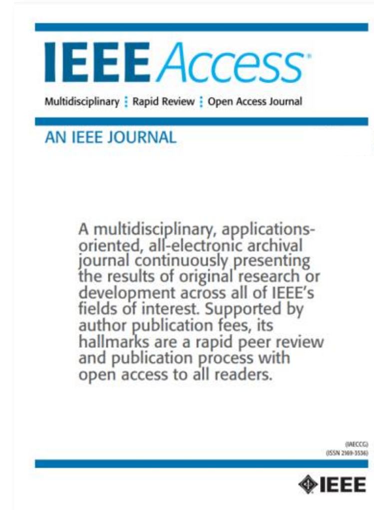

JCR

Scopus

Cortés-Murcia, D.L., et al., 2022. Supply chain management, game-changing technologies, and Physical Internet: a systematic meta-review of literature. *IEEE Access*, 10, 61721–61743.

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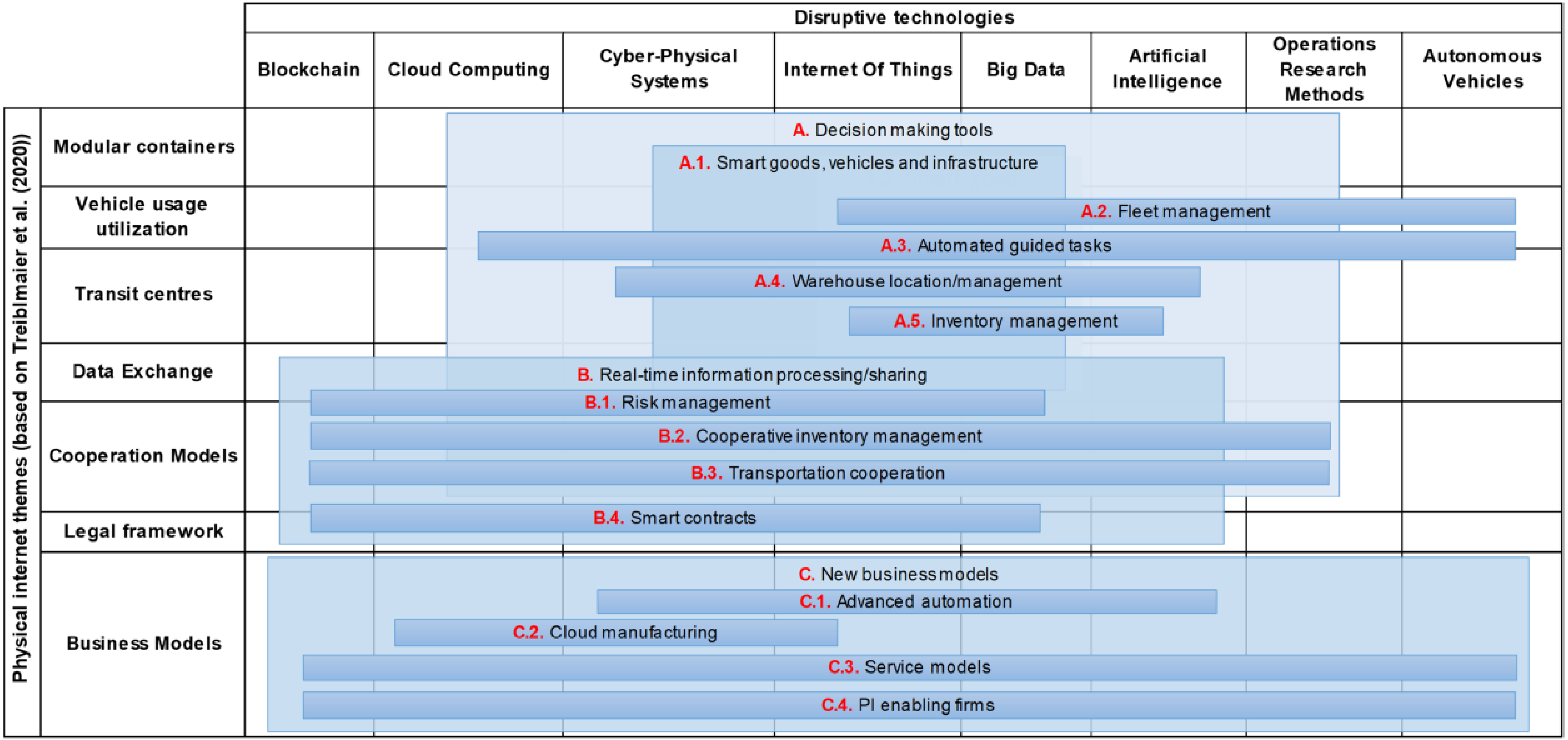
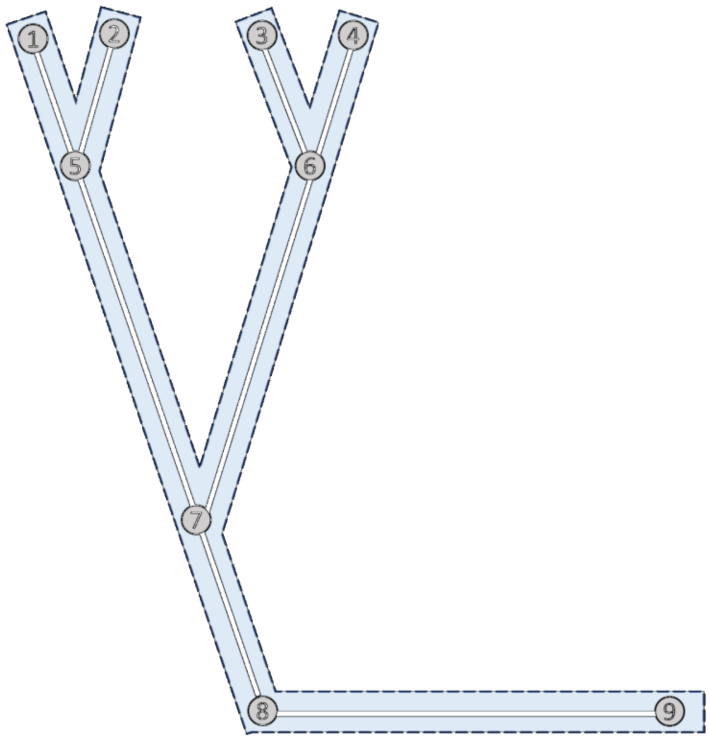
WP1. Vision, opportunities and requirements

- We present a conceptual framework that summarizes the existing relationships between relevant disruptive technologies, the PI topics, and supply chain key activities.
- The framework is helpful for researchers and practitioners:
  - to find potential technologies to invest in,
  - to assess the potential effects on companies of their implementation,
  - and to support strategic decision-making.

WP1. Vision, opportunities and requirements



Freight transportation on rivers (inland waterways):



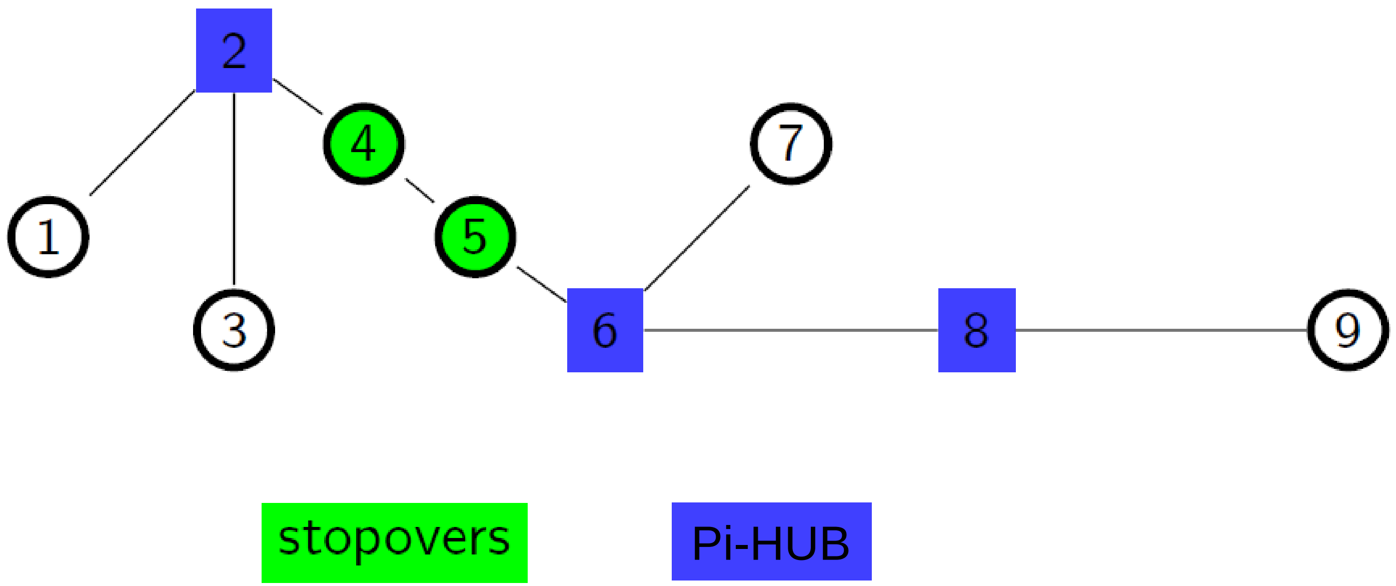
River transport is a solution to faster, more sustainable, and more cost-effective logistics

River waterway services are severely limited by a lack of infrastructure (Flexport.com, 2022)

Where to locate PI-Hubs in this setting?

Freight transportation on rivers (inland waterways):

Where to locate PI-Hubs in this setting?



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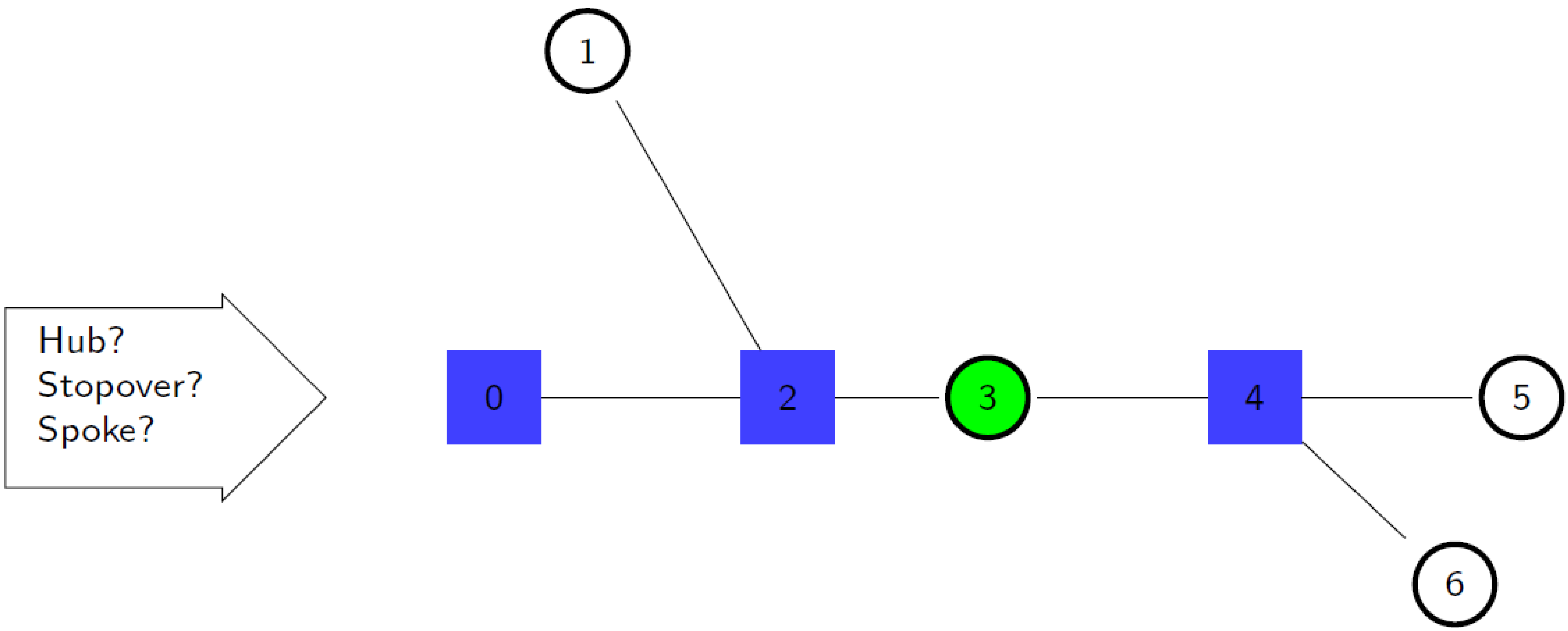
Problem decisions:

- Hub and stopover location
- Spokes allocation



Freight transportation on rivers (inland waterways):

Minimize total transportation costs, including the opening of hubs.
The transportation costs corresponds to the transportation of commodities from an origin i to a destination j.

$$minimize \quad \sum_{i \in N} \sum_{k \in N} (C_{ik} O_i + C_{ki} D_i) Z_{ik} + \sum_{i \in N} \sum_{k \in N} \sum_{l \in N} \alpha C_{kl} X_{ikl} + \sum_{i \in N} \sum_{k \in N} \sum_{l \in N} \beta C_{kl} X'_{ikl} + \sum_{k \in N} f_k Z_{kk} \quad (1)$$

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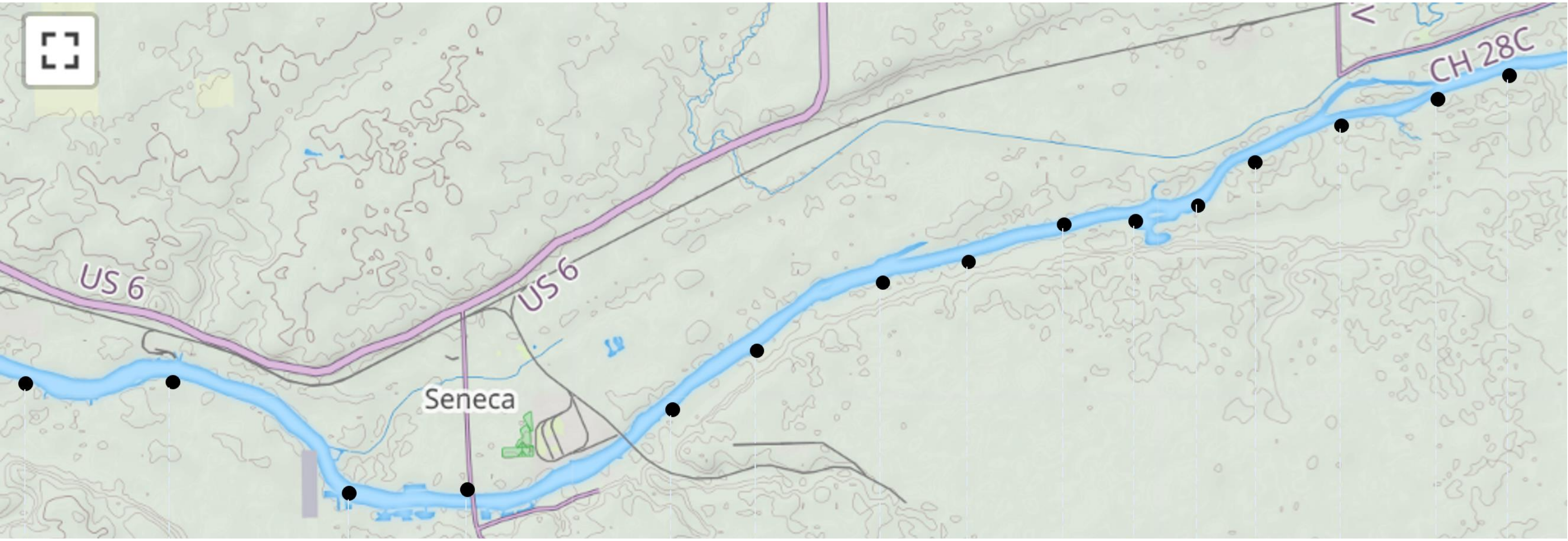
Freight transportation on rivers (inland waterways):

Illinois waterway case study



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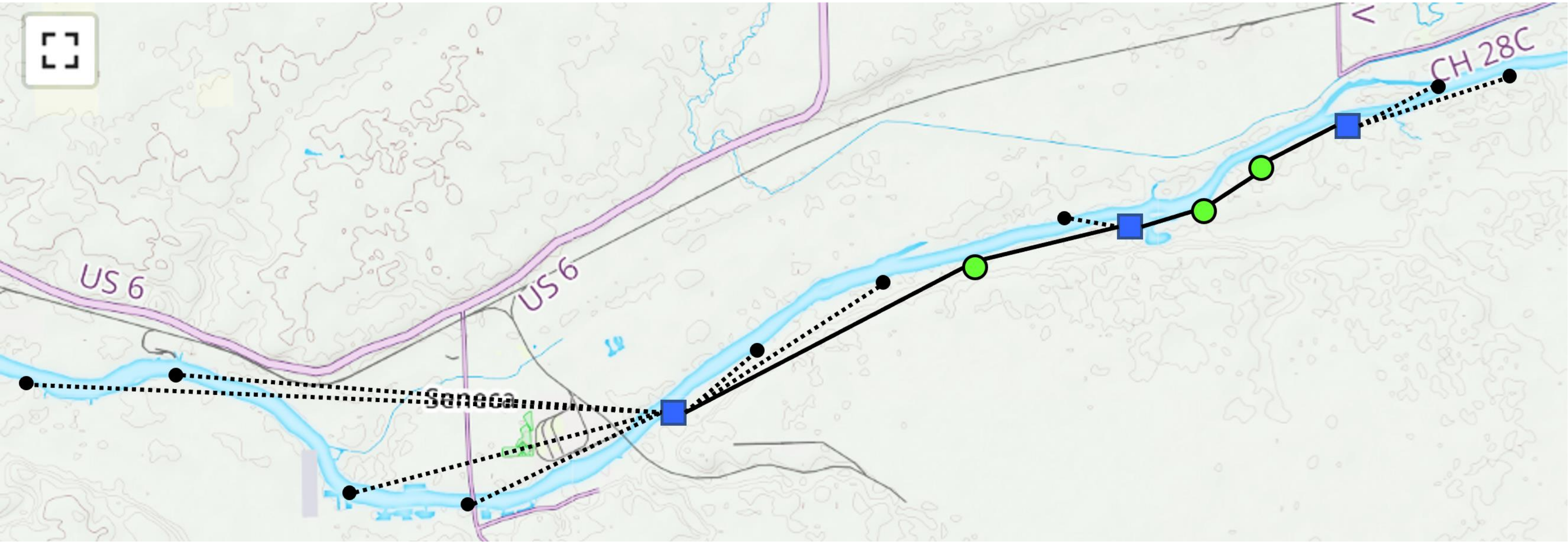
Freight transportation on rivers (inland waterways):

Illinois waterway case study



WP3. Artificial intelligence and optimization

- Transportation and logistics (T&L) activities are core functions in any modern industry.
- These functions cover all decision levels.
- Regardless of this level, the scientific literature has demonstrated that realistic T&L problems are computationally complex (NP-hard).
- Hence, optimal solutions are hard to find in short computing times.

Strategic

Tactical

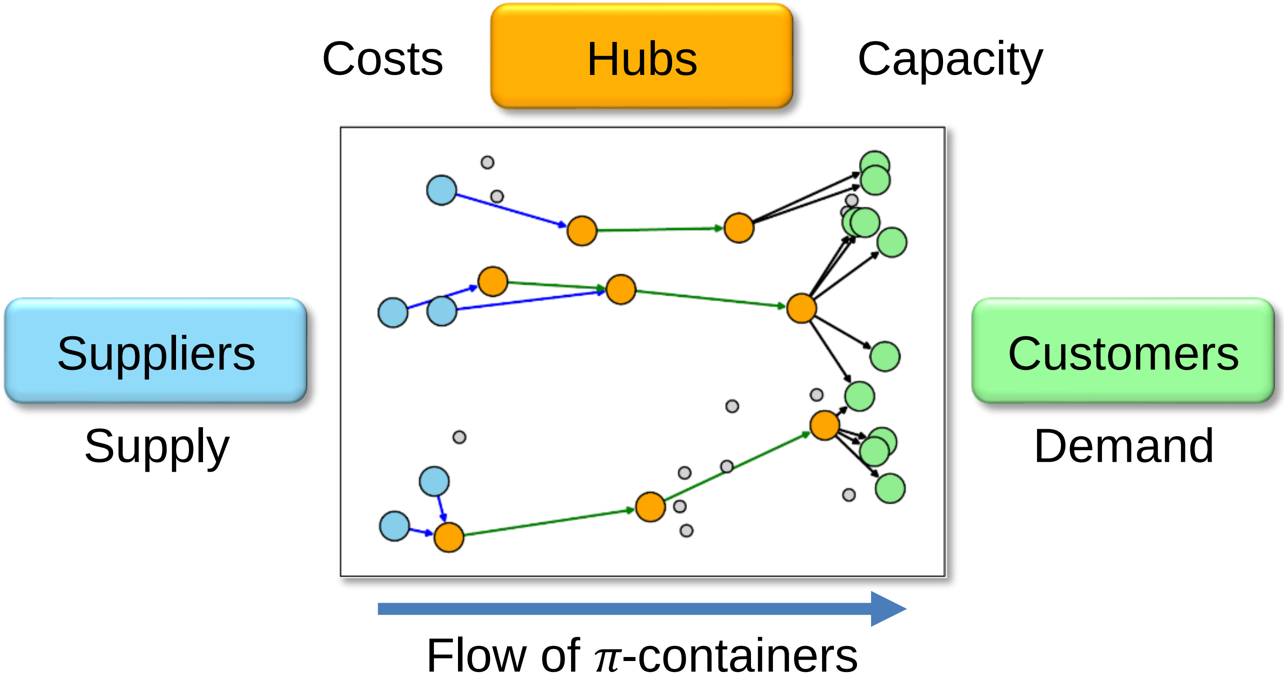
Operational

WP3. Artificial intelligence and optimization

- Different constraints and conditions make realistic T&L problems even more complex and challenging, e.g., uncertainty, sustainability or resilience.
- Agile and flexible solving methods are necessary to provide solutions to real-world problems with these characteristics.

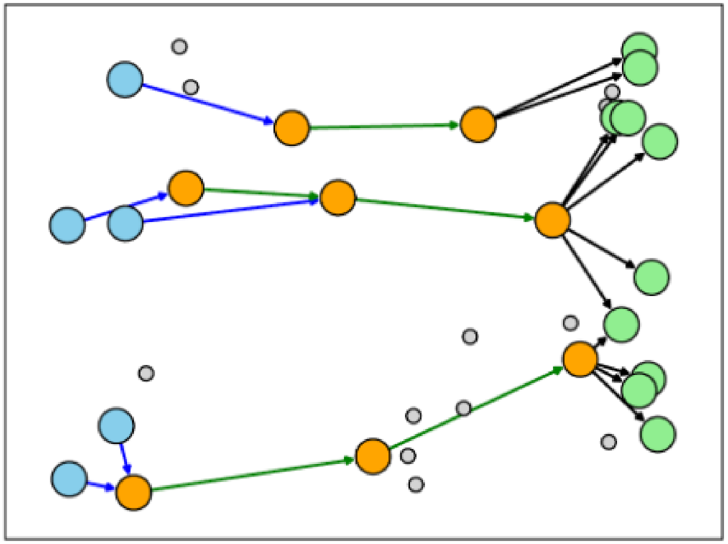
Problem description

- We consider a strategic-tactical problem to design a supply chain network (SCND), i.e., the following decisions must be made:
  - Location decisions (which hubs should be open?).
  - Allocation decisions (how to assign suppliers and customers to open hubs?).

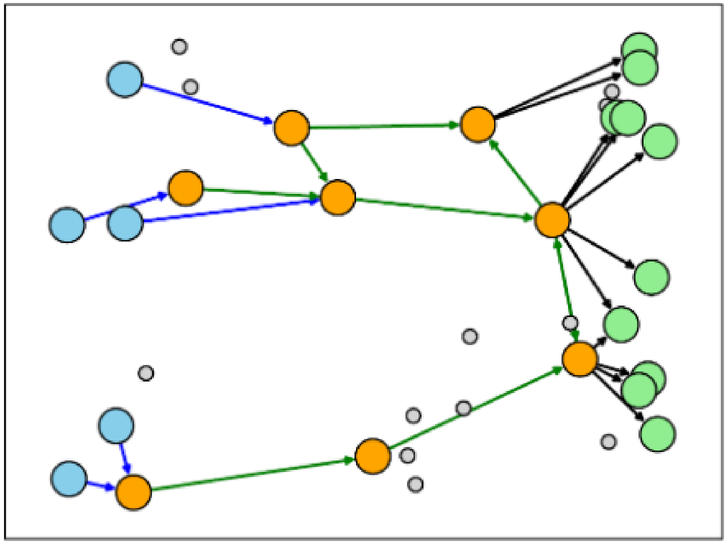


Problem variants

- A basic (B) SCND problem.
- A hyperconnected (H) SCND problem.
- A hyperconnected multi-actor (HMA) SCND problem.
- A dedicated (D) SCND problem.
- A dedicated multi-actor (DMA) SCND problem.



(a) A basic solution.



(b) A hyperconnected solution.

Objectives

- Minimize total costs, formed by:
  - Transportation costs.
  - Fixed and variable costs for managing π-containers in the hubs.

$$Minimize \sum_{t\in T}\left[\sum_{h\in H} f_h z_h + \sum_{k\in K}\left(\sum_{(h,h')\in B} g_h x_{hh'kt} + \sum_{(h,j)\in C} g_h y_{hjkt}\right) + \sum_{(i,h)\in A} ca_{ih} r_{ih} + \sum_{(h,h')\in B} cb_{hh'} u_{hh'} + \sum_{(h,j)\in C} cc_{hj} v_{hj}\right]$$

- Maximize resilience after hubs have been disturbed by any disruption event.

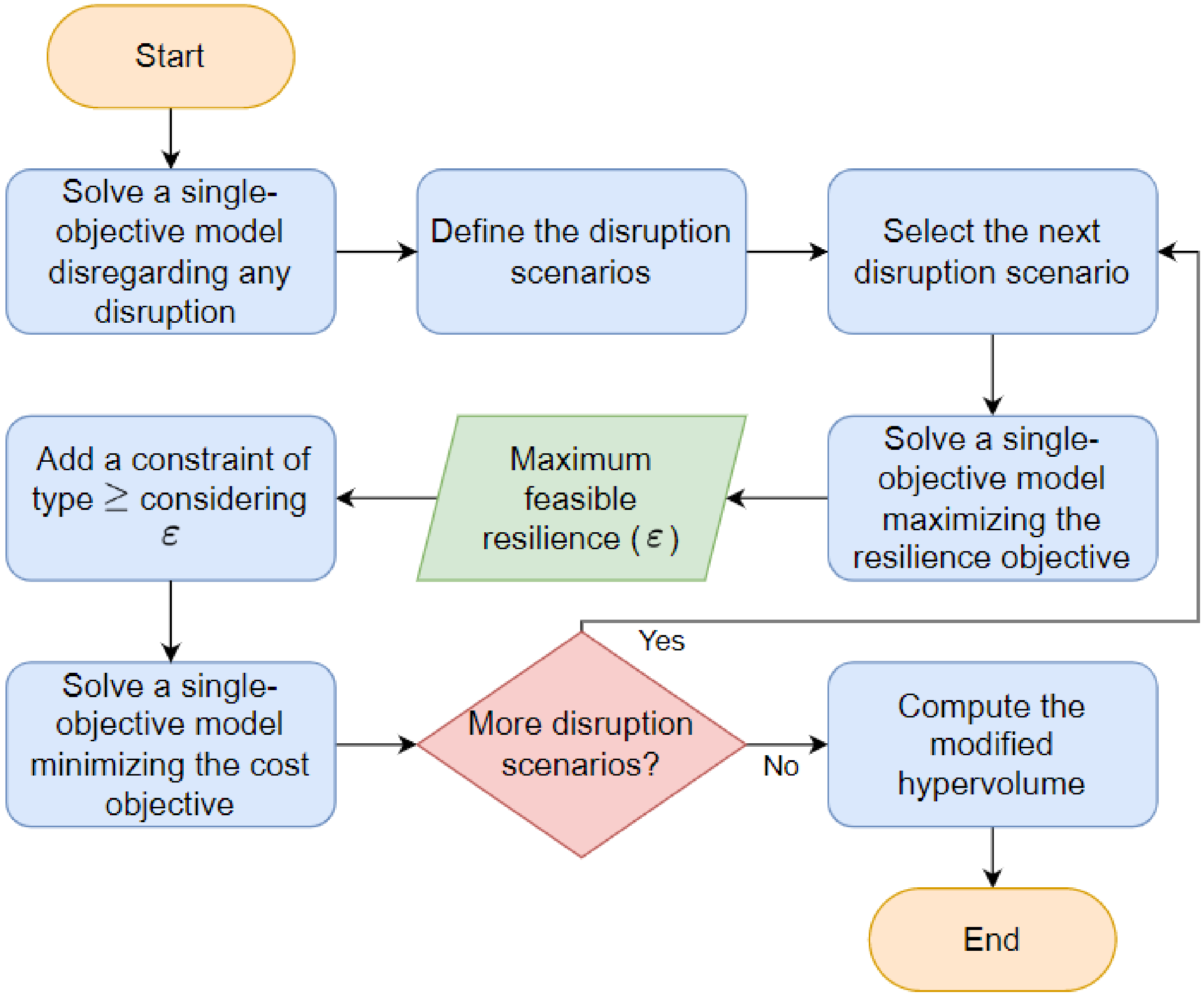
$$Maximize \frac{\sum_{t\in T\setminus t_0}\left(\frac{\sum_{k\in K}\sum_{(h,j)\in C} y_{hjkt}}{\sum_{j\in J}\sum_{k\in K} d_{jkt}} + \frac{\sum_{k\in K}\sum_{(h,j)\in C} y_{hjkt-1}}{\sum_{j\in J}\sum_{k\in K} d_{jkt-1}}\right)\Delta t}{2t^{max}}$$

Resilience is the ability of a system to return to its original state or move to a new, more desirable state after being disturbed (Christopher, & Peck, 2004)

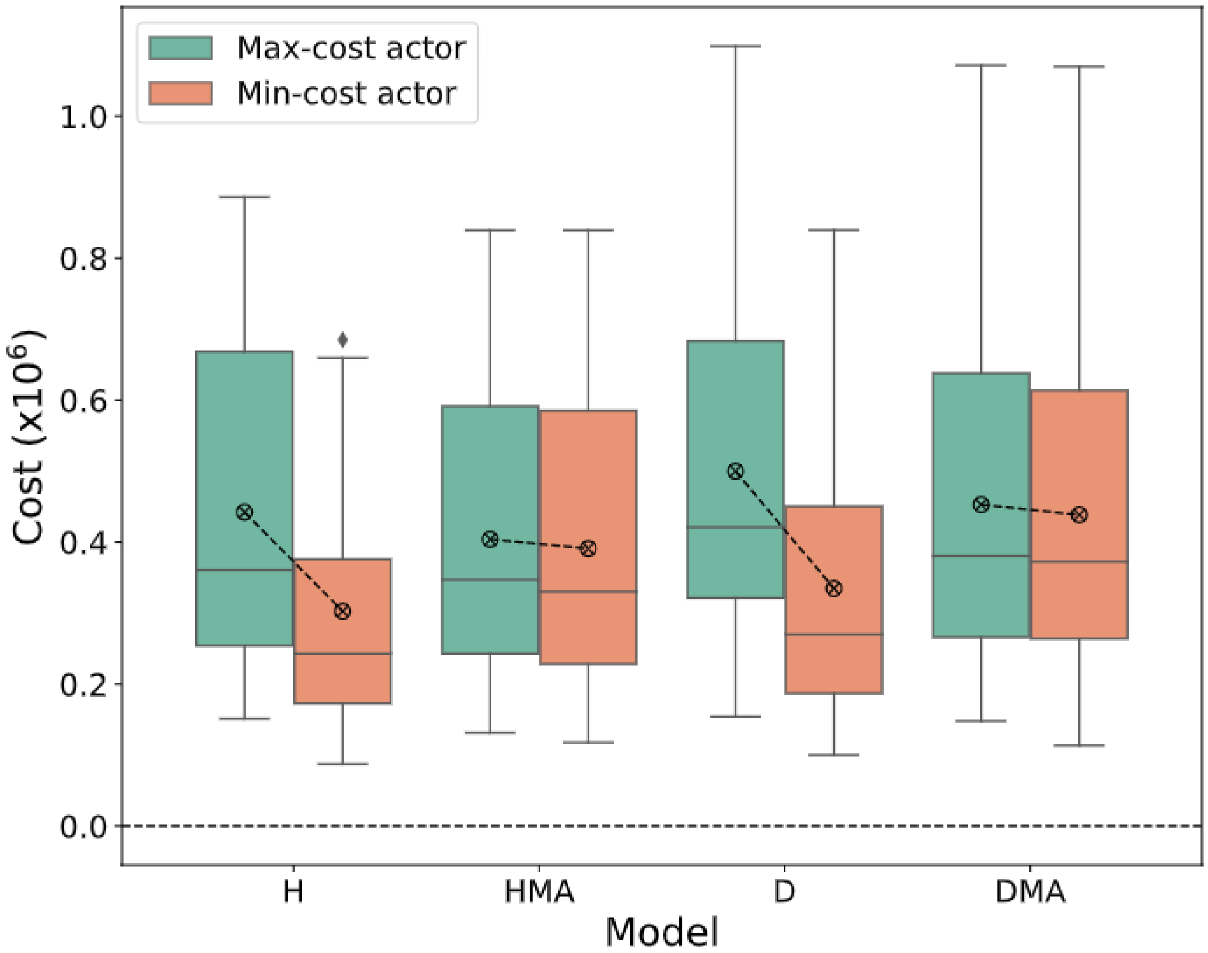
Christopher, M., & Peck, H. (2004). Building the resilient supply chain. *International Journal of Logistics Management*, 15, 1–14.

Tordecilla, R.D., et al. (2021). Simulation-optimization methods for designing and assessing resilient supply chain networks under uncertainty scenarios: A review. *Simulation Modelling Practice and Theory*, 106, 102166.

Solution approach

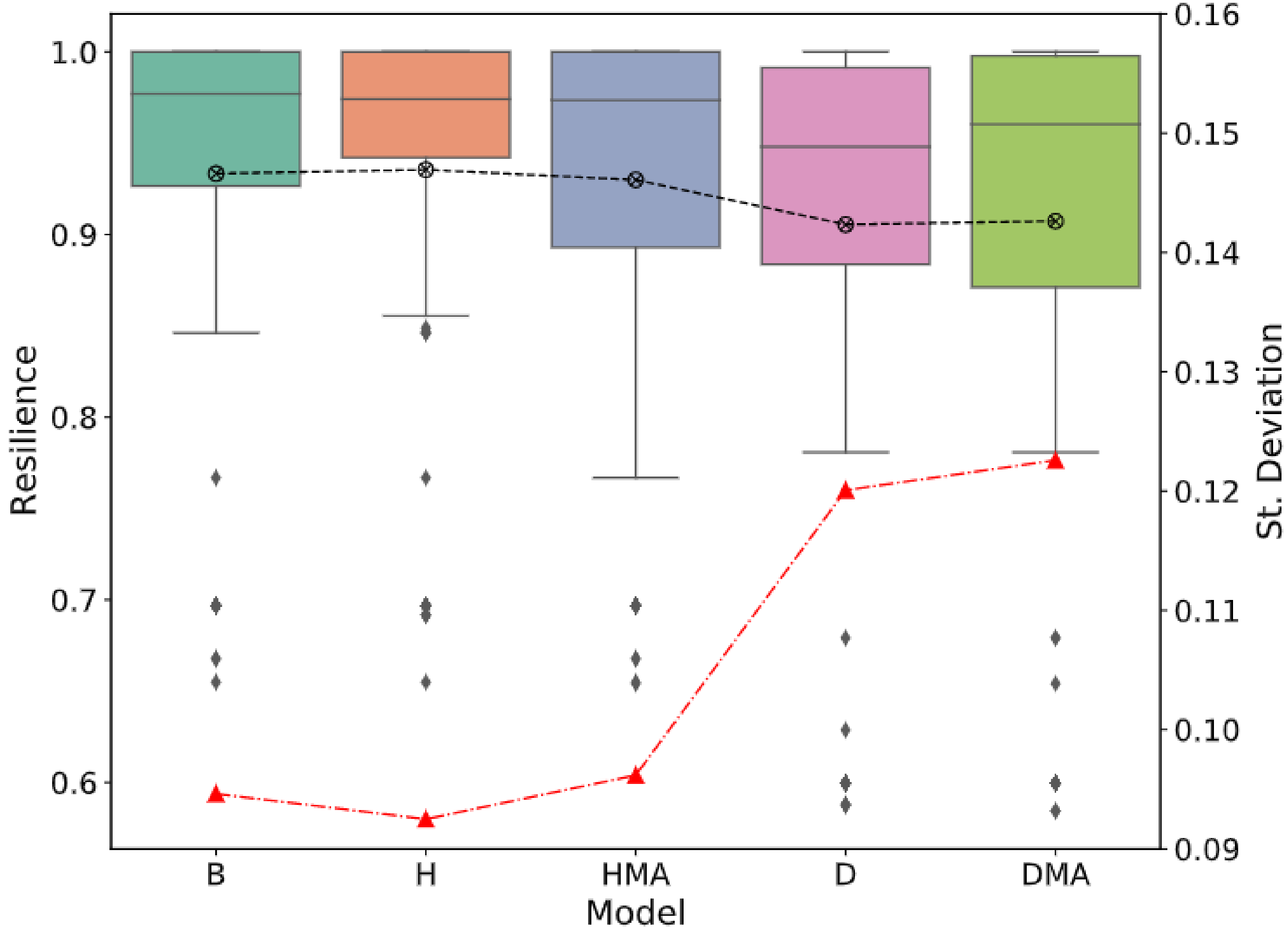


Results



Max-cost actor
Min-cost actor
1.0
0.8
0.6
0.4
0.2
0.0
Cost (x10⁶)
H
HMA
D
DMA
Model

Results



Resilience
1.0
0.9
0.8
0.7
0.6
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
St. Deviation
B
H
HMA
D
DMA
Model

Conclusions

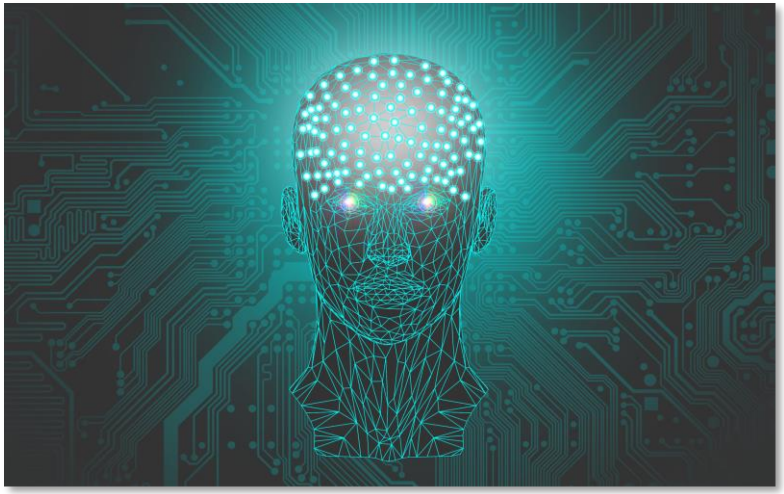
- Mathematical modelling offers a set of highly useful tools to design supply chain networks, considering multiple KPIs, such as cost or resilience, and several characteristics, such as hyperconnection or multiple actors.
- We have demonstrated that, when minimizing the maximal cost incurred by the different actors managing the hubs, equality among them increases.
- Although hyperconnection increases design costs, resilience grows as well. In the same way, hyperconnection decreases the risk faced by supply chains.

Future work

- Designing heuristic and metaheuristic methods to solve large-sized instances.
- Considering uncertainty in the studied problems, given its relevance when addressing resilience. Simulation-optimization methods and simheuristics are useful to solve efficiently this type of problems.
- Sustainability is a relevant issue to address in the Physical Internet context. Hence, it can be considered as an additional objective to optimize. Environmental and social KPIs become relevant in this case.

Web pages

- https://epicenterproject.eu/
- https://cordis.europa.eu/project/id/861584
- https://www.etp-logistics.eu/
- http://www.physicalinternetinitiative.org/
- https://www.youtube.com/watch?v=i0NwZGaPZdw
- https://www.youtube.com/channel/UC-1_szlCtw6ZTQC9PmfK9Ag/videos



Prof. Dr. William J. Guerrero
william.guerrero1@unisabana.edu.co

Dr. Rafael D. Tordecilla
rafaeltoma@unisabana.edu.co

Thank you!