



**HAL**  
open science

# Multi-objective Truck Scheduling in a Physical Internet Road-Road Cross-docking Hub

Tarik Chargui, Abdelghani Bekrar, Mohamed Reghioui, Damien Trentesaux

► **To cite this version:**

Tarik Chargui, Abdelghani Bekrar, Mohamed Reghioui, Damien Trentesaux. Multi-objective Truck Scheduling in a Physical Internet Road-Road Cross-docking Hub. 17th IFAC Symposium on Information Control Problems in Manufacturing, Jun 2021, Budapest, Hungary. pp.647-652, 10.1016/j.ifacol.2021.08.175 . hal-03408039

**HAL Id: hal-03408039**

**<https://uphf.hal.science/hal-03408039>**

Submitted on 29 Aug 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0  
International License

# Multi-objective Truck Scheduling in a Physical Internet Road-Road Cross-docking Hub

Tarik Chargui\* Abdelghani Bekrar\* Mohamed Reghioi\*\*  
Damien Trentesaux\*

\* LAMIH, UMR CNRS 8201, Université Polytechnique  
Hauts-de-France, Le Mont Houy, 59313, Valenciennes, France  
(e-mail: [tarik.chargui@gmail.com](mailto:tarik.chargui@gmail.com),  
{[abdelghani.bekrar](mailto:abdelghani.bekrar@uphf.fr), [damien.trentesaux](mailto:damien.trentesaux@uphf.fr)}@uphf.fr).

\*\* MOSIL Laboratory, National School of Applied Sciences of Tetouan,  
University of Abdelmalek Essaadi, Tetouan, Morocco  
(e-mail: [m.reghioi@gmail.com](mailto:m.reghioi@gmail.com))

**Abstract:** Aiming towards a sustainable supply chain, Physical Internet (PI) has been presented as a global logistics network with standardized PI-containers. PI-nodes, and more specifically PI-hubs, are one of the key elements of the Physical Internet concept. This paper focuses on optimising operations in the Road-Road PI-hub, which was not addressed in the Physical Internet literature. Road-Road PI-hubs are designed to transfer PI-containers between suppliers' and customers' trucks. The objective is to minimize both the inbound/outbound trucks delays and the energy consumption during the transferring of PI-containers using PI-conveyors. The problem is formulated as a multi-objective mixed integer model (MO-MIP) to find the optimal Pareto front. The mathematical model is tested on an illustrative instance to show the trade-off between trucks' delays and PI-containers routing energy consumption. The primary goal of this paper is to provide a prospect to start optimizing PI-hubs by suggesting a multi-objective mathematical model as a beginning for future researches on the Road-Road PI-hubs.

Copyright © 2021 The Authors. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0>)

**Keywords:** Logistics, Cross-docking, Physical Internet, Road-Road PI-hub, Truck scheduling, Mathematical programming, Multi-objective optimization, Optimal Pareto front.

## 1. INTRODUCTION

In the global supply chain, cross-docking is an efficient facility for transferring products between suppliers and customers from inbound to outbound vehicles such as trucks, trains, ships, etc. (Theophilus et al., 2019; Ladier and Alpan, 2016; Van Belle et al., 2012). Distributing products in an efficient and also sustainable way is becoming a challenge for many logistics and transportation companies. In this context, Physical Internet (PI) has been presented as a possible solution among many other ambitious concepts (Internet of Things (Witkowski, 2017; Liu et al., 2019), Industry 4.0 (Facchini et al., 2020; Tang and Veulenturf, 2019; Kostrzewski et al., 2020), etc). Physical Internet aims to create a global logistics network in which the storage and transportation resources are shared between suppliers, distribution centres, and clients. PI is based on the idea of encapsulating products in smart PI-containers which are designed to be interconnected and easy to handle and store. This logistics network is designed to be economically, environmentally, and socially sustainable (Montreuil et al., 2013a; Zhong et al., 2017).

Physical Internet is composed of three key elements: PI-containers, PI-movers and PI-nodes (Montreuil et al., 2013b). PI-containers are smart sustainable containers with standardized dimensions. PI-movers are used to

move the PI-containers through the Physical Internet (PI-locomotives, PI-trucks, etc). Finally, PI-nodes are transit centres to transfer PI-containers between different types of vehicles:

**Road→Rail PI-hubs:** This category of PI-hubs is used to transfer PI-containers from the incoming trucks to the outgoing trains (Ballot et al., 2012; Chargui et al., 2019b).

**Rail→Road PI-hubs:** Their main function is to move PI-containers in the opposite direction of the Road-Rail PI-hub, from the inbound trains to the outbound trucks (Vo et al., 2018; Chargui et al., 2019a; Walha et al., 2016).

**Rail↔Road PI-hubs:** Move the PI-containers in both directions between trains and trucks (Chargui et al., 2019c).

**Water↔Road PI-hubs:** Manage the transfer of PI-containers between ships and trucks (Montreuil et al., 2013b).

**Road↔Road PI-hubs:** Those PI-hubs handle the transferring of PI-containers between inbound and outbound trucks (Meller et al., 2012; Chargui et al., 2019d).

This paper focuses on the last type of PI-hubs. The Road-Road PI-hubs have not been studied yet from a multi-

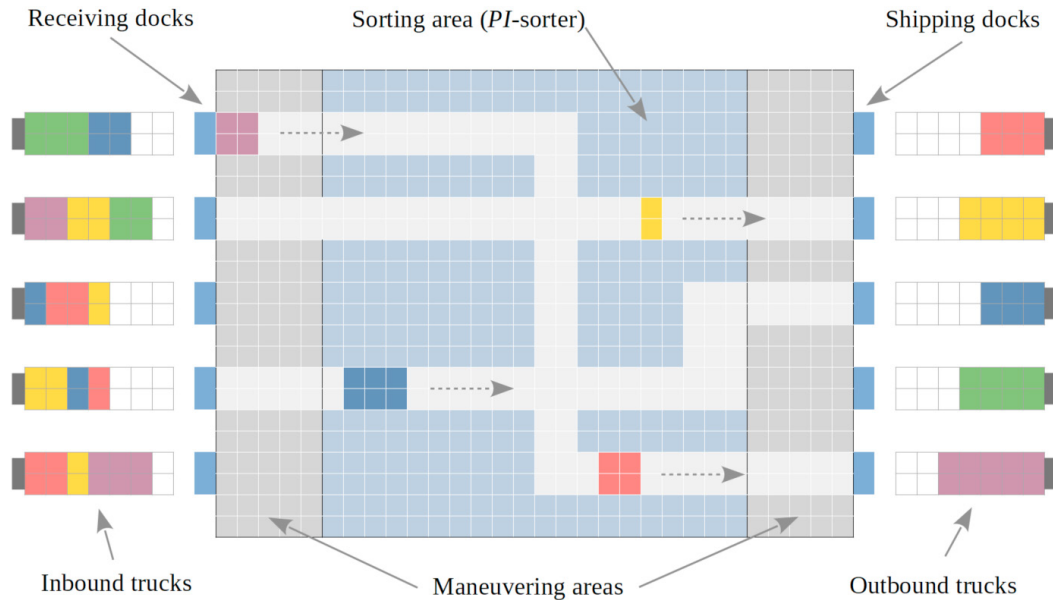


Fig. 1. Functional design of the Road-Road PI-hub

objective perspective. The objective of this paper is to mathematically formulate and solve the truck scheduling and PI-containers routing as a multi-objective mixed integer mathematical model (MO-MIP). The objective is to find the optimal Pareto front by minimizing both the trucks delays and the energy used for the routing of PI-containers between inbound and outbound trucks.

The remaining of this paper is structured as follows: Section 2 presents the functional design of the studied Road-Road PI-hub and the literature of the cross-docking hubs in the Physical Internet context. The proposed multi-objective mathematical model is presented in Section 3. Section 4 analyses the experimental results. Finally, Section 5 concludes the work with several future directions.

## 2. LITERATURE REVIEW

This section presents the functional design of the Road-Road cross-docking PI-hub, followed by a review on the literature of cross-docking problems in the Physical Internet context.

### 2.1 Functional design of the Road-Road PI-hub

In the Physical Internet context, Road-Road PI-hubs are designed to transfer PI-containers from suppliers' incoming trucks to customers' outgoing trucks through a sorting area as illustrated in Fig. 1. In the first step, PI-containers are automatically unloaded from the inbound trucks at the PI-docks and then routed to the manoeuvring area for shipping at the outbound docks. In the sorting area (PI-sorter), the PI-containers slide on the PI-conveyors units until they arrive at the shipping side. The inbound and outbound trucks arrive at a specific time and are preferred to leave at a specific departure time. The objective is to minimize the trucks tardiness as well as the energy used to move the PI-containers in the PI-sorter zone. The problem is formulated mathematically in section 3.

### 2.2 Related works in the Physical Internet context

The recent researches on Physical Internet are more focused on the optimization of the global supply chain process (Rodríguez Cornejo et al., 2020; Pan et al., 2019). For instance, Peng et al. (2020) formulated mathematically the integrated production inventory distribution network to evaluate the sustainability performance in Physical Internet. The results confirm the ability of the PI to improve the sustainability while increasing the vehicles utilization. Dynamic and integer programming can also be coupled to solve less-than-truckload carriers in the Physical Internet (Qiao et al., 2020). Other studies, such as in Gumzej et al. (2020), focus on designing intelligent transport unit for the air transport in Physical Internet. Other researches such as in Kantasa-ard et al. (2020) address the PI logistics network from a machine learning perspective for demand forecasting. The performance of their approach was then evaluated on a real case study. All the researches above focus on the whole supply chain process.

PI-nodes, and more specifically PI-hubs, have been addressed with different approaches in recent years. Rail-Road PI-hubs were widely addressed in the Physical Internet literature especially from a multi-agent simulation prospect by developing control architectures using multi-agent systems for PI-containers routing (Vo et al., 2018; Chargui et al., 2019b; Pach et al., 2014) or to optimize the assignment of trucks and the grouping of PI-containers (Walha et al., 2016; Chargui et al., 2018). Other researches coupled simulation with optimization to generate robust solutions for Road-Road PI-hubs (Chargui et al., 2019d) and the two-way Road-Rail PI-hubs (Chargui et al., 2019c).

Multi-objective approaches are becoming more common in the cross-docking literature (Theophilus et al., 2019). However, most of the previous studies on PI-hubs either use a given lexicographic order for the objective functions (Chargui et al., 2019a) or a weighted sum for prioritizing objectives (Chargui et al., 2019b; Walha et al., 2016).

Since optimization studies on Road-Road PI-hubs have not been addressed yet, this paper proposes a multi-objective mathematical programming model (MO-MIP) to determine the optimal Pareto front for the trade-off between the trucks tardiness and energy consumption of the routing of PI-containers. The next section (Section 3) provides the notations for the parameters, decision variables, the normalized weighted sum of the objective functions, and the constraints.

### 3. MATHEMATICAL FORMULATION

This section presents the mathematical formulation of the problem as a multi-objective mixed integer programming model (MO-MIP).

#### 3.1 Input data and parameters

- $N^I$  Number of inbound trucks
- $N^O$  Number of outbound trucks
- $M^I$  Number of inbound docks
- $M^O$  Number of outbound docks
- $N^C$  Total number of PI-containers
- $P_k^I$  Position of receiving dock  $k$
- $P_l^O$  Position of shipping dock  $l$
- $Y$  Number of PI-conveyors from receiving side to shipping side
- $A_i^I$  Arrival time of inbound truck  $i$
- $D_i^I$  Preferred departure time of inbound truck  $i$
- $A_j^O$  Arrival time of outbound truck  $j$
- $D_j^O$  Preferred departure time of outbound truck  $j$
- $L_c^C$  Length of PI-container  $c$  ( $\times 1.2m$ )
- $G_{ij}$  Binary PI-containers flow matrix between inbound and outbound trucks ( $G_{ij} = 1$  if there is at least one PI-container moving from inbound truck  $i$  to outbound truck  $j$ , 0 otherwise)
- $B_{ic}^I = 1$  if inbound truck  $i$  contains PI-container  $c$ , 0 otherwise
- $B_{jc}^O = 1$  if PI-container  $c$  will be shipped into outbound truck  $j$ , 0 otherwise
- $U$  Time to load/unload one PI-container from trucks
- $T$  Number of time units to move a PI-container from a PI-conveyor unit to another
- $E$  Trucks changeover time
- $C^E$  Energy cost for one PI-conveyor move
- $M$  A big positive number

#### 3.2 Decision variables

- $s_i^I$  Unloading start time of inbound truck  $i$
- $e_i^I$  Unloading end time of inbound truck  $i$
- $s_j^O$  Loading start time of outbound truck  $j$
- $e_j^O$  Loading end time of outbound truck  $j$
- $\sigma_c$  Number of PI-conveyors used to move PI-container  $c$  from inbound dock to outbound dock
- $x_{ik} = 1$  if inbound truck  $i$  is assigned to receiving dock  $k$ , 0 otherwise
- $y_{jl} = 1$  if outbound truck  $j$  is assigned to shipping dock  $l$ , 0 otherwise
- $p_{im} = 1$  if inbound truck  $i$  is unloaded before inbound truck  $m$ , 0 otherwise
- $q_{jn} = 1$  if outbound truck  $j$  is loaded before outbound truck  $n$ , 0 otherwise

- $h_{ijkl} = 1$  if inbound truck  $i$  is assigned to receiving dock  $k$  and outbound truck  $j$  is assigned to shipping dock  $l$  while  $G_{ij} = 1$ , 0 otherwise
- $\alpha$  Weighting factor for  $F^T$  and  $F^E$  ( $\alpha \in [0, 1]$ )
- $I_{FT}$  The optimal value for  $F^T$  while  $\alpha = 1$
- $I_{FE}$  The optimal value for  $F^E$  while  $\alpha = 0$
- $N_{FT}$  The best value of  $F^T$  corresponding to the optimal value of  $F^E$
- $N_{FE}$  The best value of  $F^E$  corresponding to the optimal value of  $F^T$

#### 3.3 Objective function: Normalized weighted sum

There are two objective functions in this model, the first one is the inbound and outbound trucks tardiness  $F^T$ , the second objective is the total energy consumed by the PI-conveyors in the sorting area  $F^E$ . Since the two objectives have different measuring units (time units for  $F^T$  and energy cost for  $F^E$ ), it necessary to normalize both objectives. In this case, we use the Nadir and Ideal points as used in Demir et al. (2014). The Ideal point ( $I_{FT}$ ,  $I_{FE}$ ) presents the best possible values of both  $F^T$  and  $F^E$ . In Nadir point ( $N_{FT}$ ,  $N_{FE}$ ),  $N_{FT}$  is the best value of  $F^T$  corresponding to the optimal value of  $F^E$ , and  $N_{FE}$  is the best value of  $F^E$  when  $F^T$  is at its optimal value. The obtained formulation is presented in Equation 1.

$$\text{Minimize: } \alpha F^T + (1 - \alpha) F^E$$

Where:

$$F^T = \frac{\sum_{i=1}^{N^I} (e_i^I - D_i^I) + \sum_{j=1}^{N^O} (e_j^O - D_j^O) - I_{FT}}{N_{FT} - I_{FT}} \quad (1)$$

$$F^E = \frac{\left( \sum_{c=1}^H C_c^E \sigma_c \right) - I_{FE}}{N_{FE} - I_{FE}}$$

#### 3.4 Trucks assignment constraints

Equations 2 and 3 ensure that each inbound/outbound truck is handled by one dock.

$$\sum_{k=1}^{M^I} x_{ik} = 1 \quad (\forall i = 1 \dots N^I) \quad (2)$$

$$\sum_{l=1}^{M^O} y_{jl} = 1 \quad (\forall j = 1 \dots N^O) \quad (3)$$

Equations 4 - 6 calculate the value of  $h_{ijkl}$  using the trucks assignment  $x_{ik}$  and  $y_{jl}$  and the flow matrix  $G_{ij}$

$$\sum_{k=1}^{M^I} \sum_{l=1}^{M^O} h_{ijkl} = G_{ij} \quad (\forall i = 1 \dots N^I, \forall j = 1 \dots N^O) \quad (4)$$

$$h_{ijkl} \leq x_{ik} \quad (\forall i = 1 \dots N^I, \forall j = 1 \dots N^O, \forall k = 1 \dots M^I, \forall l = 1 \dots M^O) \quad (5)$$

$$h_{ijkl} \leq y_{jl} \quad (\forall i = 1 \dots N^I, \forall j = 1 \dots N^O, \forall k = 1 \dots M^I, \forall l = 1 \dots M^O) \quad (6)$$

Equations 7 - 10 handle the sequencing of the inbound/outbound trucks if they are assigned to the same receiving/shipping dock. Equations 7 and 8 ensure that an inbound/outbound truck does not precede itself ( $p_{mm} = 0$  or  $p_{nn} = 0$ ). Equations 9 and 10 calculate the values of  $p_{im}$  and  $p_{jn}$  using the assignment variables  $x_{ik}$  and  $y_{jl}$ .

$$p_{im} + p_{mi} \leq 1 \quad (\forall i, m = 1 \dots N^I) \quad (7)$$

$$q_{jn} + q_{nj} \leq 1 \quad (\forall j, n = 1 \dots N^O) \quad (8)$$

$$x_{ik} + x_{mk} - 1 \leq p_{im} + p_{mi} \quad (\forall i, m = 1 \dots N^I, \forall k = 1 \dots M^I : i \neq m) \quad (9)$$

$$y_{jl} + y_{nl} - 1 \leq q_{jn} + q_{nj} \quad (\forall j, n = 1 \dots N^O, \forall l = 1 \dots M^O : j \neq n) \quad (10)$$

### 3.5 Truck scheduling constraints

Equation 11 guarantees that each inbound truck starts unloading after arriving at the dock. The starting and ending time of unloading inbound trucks is calculated using Equations 12 - 13.

$$s_i^I \geq A_i^I \quad (\forall i = 1 \dots N^I) \quad (11)$$

$$s_m^I \geq e_i^I + E - M(1 - p_{im}) \quad (\forall i, m = 1 \dots N^I) \quad (12)$$

$$e_i^I \geq s_i^I + U \sum_{c=1}^{N^C} B_{ic}^I \quad (\forall i = 1 \dots N^I) \quad (13)$$

Equation 14 ensures that all the outbound trucks start loading PI-containers after their arrival at the docks. Equations 15 - 17 calculate the start/end time of loading outgoing trucks while considering both the loading time (Equation 16) and the transfer time from inbound to outbound docks (Equation 17).

$$s_j^O \geq A_j^O \quad (\forall j = 1 \dots N^O) \quad (14)$$

$$s_n^O \geq e_j^O + E - M(1 - q_{jn}) \quad (\forall j, n = 1 \dots N^O) \quad (15)$$

$$e_j^O \geq s_j^O + U \sum_{c=1}^{N^C} B_{jc}^O \quad (\forall j = 1 \dots N^O) \quad (16)$$

$$e_j^O \geq s_j^O + U \sum_{c=1}^{N^C} B_{jc}^O + T(|P_k^I - P_l^O| + Y) - M(1 - h_{ijkl}) \quad (\forall i = 1 \dots N^I, \forall j = 1 \dots N^O, \forall k = 1 \dots M^I, \forall l = 1 \dots M^O) \quad (17)$$

### 3.6 PI-conveyors utilization

Equation 18 calculates the number of conveyors used for transferring each PI-container  $c$  from receiving docks to shipping docks.

$$\sigma_c \geq L_c^C |P_k^I - P_l^O| + 2Y - M(3 - (B_{ic}^I + B_{jc}^O + h_{ijkl})) \quad (\forall c = 1 \dots N^C, \forall i = 1 \dots N^I, \forall j = 1 \dots N^O, \forall k = 1 \dots M^I, \forall l = 1 \dots M^O) \quad (18)$$

Equations 19 and 20 ensure that the variables are respectively positive or binary.

$$s_i^I, e_i^I, s_j^O, e_j^O, \sigma_c, \alpha, I_{FT}, I_{FE}, N_{FT}, N_{FE} \geq 0 \quad (\forall c = 1 \dots N^C, \forall i = 1 \dots N^I, \forall j = 1 \dots N^O, \forall k = 1 \dots M^I, \forall l = 1 \dots M^O) \quad (19)$$

$$x_{ik}, y_{jk}, p_{im}, q_{jn}, h_{ijkl} \in \{0, 1\} \quad (\forall i, m = 1 \dots N^I, \forall j, n = 1 \dots N^O, \forall k = 1 \dots M^I, \forall l = 1 \dots M^O) \quad (20)$$

## 4. A NUMERICAL EXAMPLE

In order to illustrate the trade-off between the two objectives ( $F^T$  and  $F^E$ ), the proposed mathematical model (MO-MIP) is tested on a random illustrative instance. The model is developed on IBM CPLEX solver (version 12.9). The test is performed on a 2.5 GHz laptop with 4 GB of RAM. The values of the parameters used in the instance are summarized in Table 1.

Table 1. Values of parameters in the instance

Parameters	Values	Parameters	Values
$N^I + N^O$	8 + 8	$G_j^i, B^I, B^O$	Binary matrix
$M^I + M^O$	5 + 5	$L_i^C$	[2,5]
$N^C$	24	$U$	10
$A_i^I$	[12,124]	$T$	2
$D_i^I$	[32,144]	$E$	5
$A_j^O$	[33,160]	$Y$	30
$D_j^O$	[53,180]	$C^E$	1.2

The obtained results are presented in Table 2. The first column shows the value of  $\alpha$  from 0.0 to 1.0 with a step of 0.1. The second and third columns present the tardiness of inbound and outbound trucks respectively. Columns 4 and 5 show the values of both objective function  $F^T$  and  $F^E$ . The last column provides the computational time in seconds.

Table 2. Detailed results for  $0 \leq \alpha \leq 1$

$\alpha$	$F^T$ (Inb.)	$F^T$ (Outb.)	$F^T$	$F^E$	Time (s)
0.0	511	1597	2108	1728	4.24
0.1	511	1597	2108	1728	172.69
0.2	282	1035	1317	1747.2	566.8
0.3	282	1035	1317	1747.2	114.44
0.4	282	1035	1317	1747.2	68.11
0.5	168	844	1012	1776	86.86
0.6	168	844	1012	1776	153.13
0.7	97	798	895	1795.2	90.34
0.8	89	703	792	1824	89.45
0.9	80	688	768	1843.2	63.31
1.0	80	661	741	1872	8.62
Average	231.81	985.18	1217	1780.36	128.91

Those results are illustrated in Fig. 3. As it can be noticed for the two objective functions  $F^T$  and  $F^E$ , when trucks' tardiness decreases, the energy consumption slightly increases. Fig. 2 shows the optimal Pareto front obtained for both objectives. The coefficient  $\alpha$  remains a tuning parameter that can be set by the PI-hub manager depending on the priorities of the hub facility.

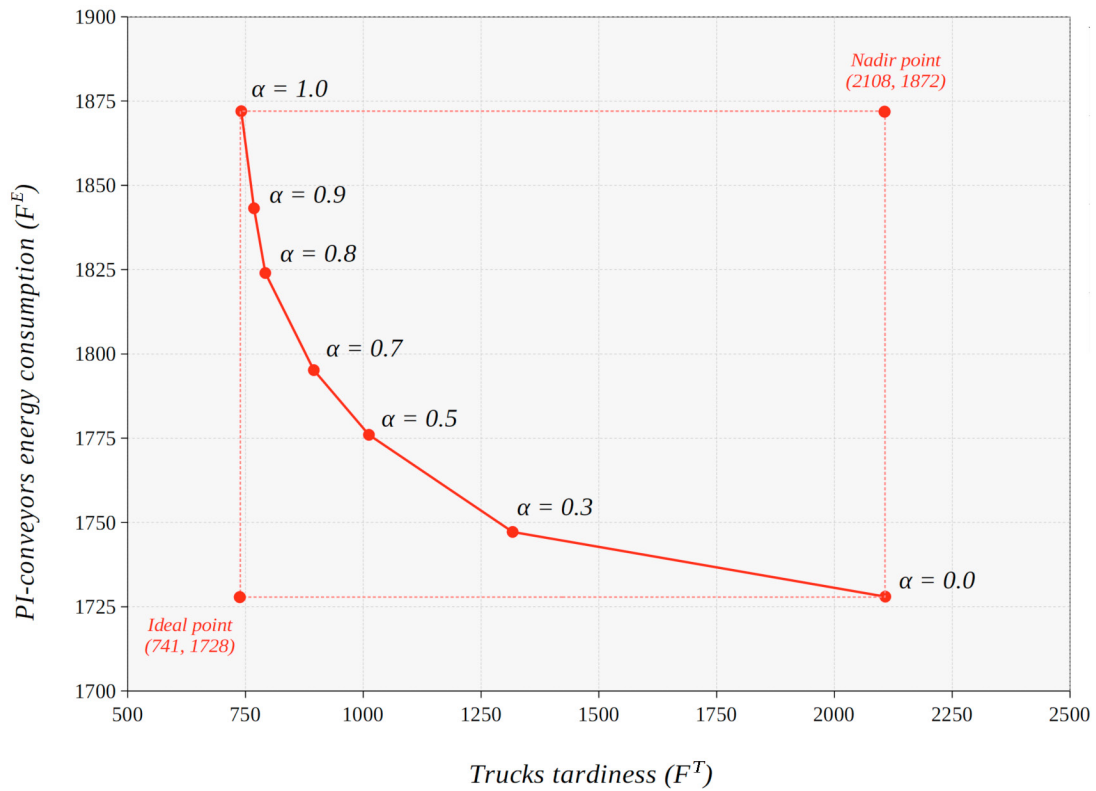


Fig. 2. The optimal Pareto front for  $F^T$  and  $F^E$

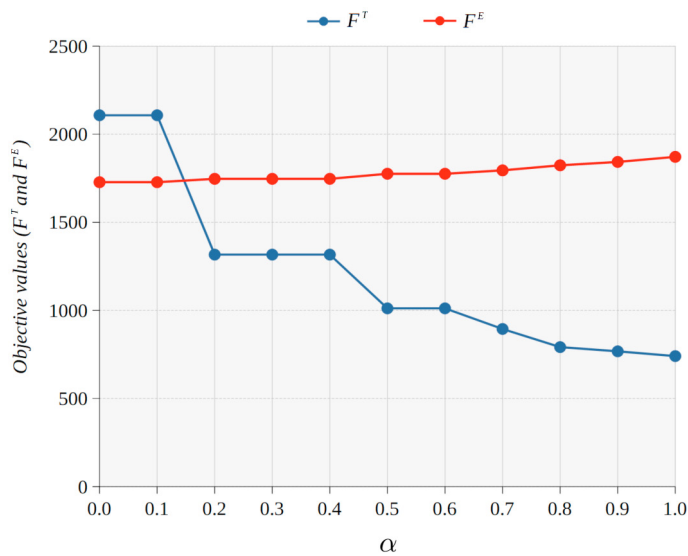


Fig. 3. Objective functions ( $F^T$  and  $F^E$ ) for  $\alpha \in [0, 1]$

5. CONCLUSION

The main objective in this research was to study the Road-Road Physical Internet hub which has not been addressed in the literature especially from a multi-objective perspective. This paper focused the truck scheduling and PI-containers routing in a Road-Road PI-hub. A multi-objective mixed integer programming model was proposed and solved to find the optimal Pareto front. The objective was to minimize the inbound and outbound trucks tardiness in addition to the PI-conveyors energy consumption when transferring PI-containers.

Through this research, the authors wish to give the opportunity to start new researches on Road-Rail PI-hubs optimization by formulating the problem mathematically from a multi-objective perspective. As a future direction of this work, it would be interesting to develop other solution methods such as meta-heuristics that can be incorporated into decision support tools to help the PI-hub managers in their daily operational tasks. Another important opportunity for future research is to consider the possible disruptions on receiving and shipping docks or in the PI-conveying system or unexpected truck delays. To deal with such disruptions, there are various approaches that can be developed, such as simulation-optimization by incorporating a simulator into the meta-heuristic to generate robust solutions or multi-agent simulation to generate alternative solutions in real time.

ACKNOWLEDGEMENTS

The work presented in this paper was supported by the ELSAT2020 project of CPER sponsored by the French ministry of sciences, the Hauts-de-France region and the FEDER.

REFERENCES

Ballot, E., Montreuil, B., and Thivierge, C. (2012). Functional design of physical internet facilities: a road-rail hub. In *12th IMHRC Proceedings, Gardanne, France*.  
 Chargui, T., Bekrar, A., Reghioui, M., and Trentesaux, D. (2018). A mathematical formulation and tabu search approach for the road-rail assignment problem. In *Proceedings of 5th International Physical Internet Conference (IPIC 2018), Groningen, The Netherlands*.

- Chargui, T., Bekrar, A., Reghioiu, M., and Trentesaux, D. (2019a). Multi-objective sustainable truck scheduling in a rail-road physical internet cross-docking hub considering energy consumption. *Sustainability*, 11(11), 3127.
- Chargui, T., Bekrar, A., Reghioiu, M., and Trentesaux, D. (2019b). Proposal of a multi-agent model for the sustainable truck scheduling and containers grouping problem in a road-rail physical internet hub. *International Journal of Production Research*, 58(18), 5477–5501.
- Chargui, T., Bekrar, A., Reghioiu, M., and Trentesaux, D. (2019c). A simulation-optimization approach for two-way scheduling/grouping in a road-rail physical internet hub. *IFAC-PapersOnLine*, 52(13), 1644 – 1649. 9th IFAC Conference on Manufacturing Modelling, Management and Control MIM 2019, Berlin, Germany.
- Chargui, T., Bekrar, A., Reghioiu, M., and Trentesaux, D. (2019d). Tabu search robustness for cross-dock and pi-hub scheduling under possible internal transportation breakdowns. In T. Borangiu, D. Trentesaux, A. Thomas, and S. Cavalieri (eds.), *Service Orientation in Holonic and Multi-Agent Manufacturing*, volume 803 of *Studies in Computational Intelligence*, 295–307. Springer International Publishing.
- Demir, E., Bektaş, T., and Laporte, G. (2014). The bi-objective pollution-routing problem. *European Journal of Operational Research*, 232(3), 464–478.
- Facchini, F., Oleśków-Szłapka, J., Ranieri, L., and Urbinati, A. (2020). A maturity model for logistics 4.0: An empirical analysis and a roadmap for future research. *Sustainability*, 12(1), 86.
- Gunzej, R., Komkhao, M., and Sodsee, S. (2020). Design of an intelligent, safe and secure transport unit for the physical internet. In *International Conference on Computing and Information Technology*, 60–69. Springer.
- Kantasa-ard, A., Nouri, M., Bekrar, A., Ait el cadi, A., and Sallez, Y. (2020). Machine learning for demand forecasting in the physical internet: a case study of agricultural products in thailand. *International Journal of Production Research*, 1–25.
- Kostrzewski, M., Varjan, P., and Gnap, J. (2020). Solutions dedicated to internal logistics 4.0. In K. Grzybowska, A. Awasthi, and R. Sawhney (eds.), *Sustainable Logistics and Production in Industry 4.0: New Opportunities and Challenges*, 243–262. Springer International Publishing.
- Ladier, A.L. and Alpan, G. (2016). Cross-docking operations: Current research versus industry practice. *Omega*, 62, 145–162.
- Liu, S., Zhang, Y., Liu, Y., Wang, L., and Wang, X.V. (2019). An ‘internet of things’ enabled dynamic optimization method for smart vehicles and logistics tasks. *Journal of Cleaner Production*, 215, 806–820.
- Meller, R.D., Montreuil, B., Thivierge, C., and Montreuil, Z. (2012). Functional design of physical internet facilities: a road-based transit center. In *12th IMHRC Proceedings, Gardanne, France*.
- Montreuil, B., Meller, R.D., and Ballot, E. (2013a). Physical internet foundations. In T. Borangiu, A. Thomas, and D. Trentesaux (eds.), *Service Orientation in Holonic and Multi Agent Manufacturing and Robotics*, volume 472 of *Studies in Computational Intelligence*, 151–166. Springer Berlin Heidelberg.
- Montreuil, B., Meller, R.D., and Ballot, E. (2013b). Towards a physical internet: The impact on logistics facilities and material handling systems design and innovation. In *Proceedings of the International Material Handling Research Colloquium (IMHRC)*, 1–23.
- Pach, C., Sallez, Y., Berger, T., Bonte, T., Trentesaux, D., and Montreuil, B. (2014). Routing management in physical internet crossdocking hubs: Study of grouping strategies for truck loading. In B. Grabot, B. Vallespir, S. Gomes, A. Bouras, and D. Kiritsis (eds.), *Advances in Production Management Systems. Innovative and Knowledge-Based Production Management in a Global-Local World*, volume 438 of *IFIP Advances in Information and Communication Technology*, 483–490. Springer Berlin Heidelberg.
- Pan, S., Trentesaux, D., Ballot, E., and Huang, G.Q. (2019). Horizontal collaborative transport: survey of solutions and practical implementation issues. *International Journal of Production Research*, 57(15-16), 5340–5361.
- Peng, X.s., Ji, S.f., and Ji, T.t. (2020). Promoting sustainability of the integrated production-inventory-distribution system through the physical internet. *International Journal of Production Research*, 58(22), 6985–7004.
- Qiao, B., Pan, S., and Ballot, E. (2020). Revenue optimization for less-than-truckload carriers in the physical internet: dynamic pricing and request selection. *Computers & Industrial Engineering*, 139, 105563.
- Rodríguez Cornejo, V., Cervera Paz, Á., López Molina, L., and Pérez-Fernández, V. (2020). Lean thinking to foster the transition from traditional logistics to the physical internet. *Sustainability*, 12(15), 6053.
- Tang, C.S. and Veelenturf, L.P. (2019). The strategic role of logistics in the industry 4.0 era. *Transportation Research Part E: Logistics and Transportation Review*, 129, 1–11.
- Theophilus, O., Dulebenets, M.A., Pasha, J., Abioye, O.F., and Kavooosi, M. (2019). Truck scheduling at cross-docking terminals: a follow-up state-of-the-art review. *Sustainability*, 11(19).
- Van Belle, J., Valckenaers, P., and Cattrysse, D. (2012). Cross-docking: State of the art. *Omega*, 40(6), 827–846.
- Vo, N.V., Berger, T., Bonte, T., and Sallez, Y. (2018). Control of rail-road PI-hub: The ORCA hybrid control architecture. In T. Borangiu, D. Trentesaux, A. Thomas, and O. Cardin (eds.), *Service Orientation in Holonic and Multi-Agent Manufacturing*, volume 762 of *Studies in Computational Intelligence*, 291–302. Springer International Publishing.
- Walha, F., Bekrar, A., Chaabane, S., and Loukil, T.M. (2016). A rail-road PI-hub allocation problem: Active and reactive approaches. *Computers in Industry*, 81, 138 – 151.
- Witkowski, K. (2017). Internet of things, big data, industry 4.0–innovative solutions in logistics and supply chains management. *Procedia Engineering*, 182, 763–769.
- Zhong, R.Y., Xu, C., Chen, C., and Huang, G.Q. (2017). Big data analytics for physical internet-based intelligent manufacturing shop floors. *International journal of production research*, 55(9), 2610–2621.