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Evaluate the Potential of the Physical Internet for Last Mile Delivery in Developing Countries

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Abstract. Last mile delivery is a crucial component of the supply chain process, particularly in developing countries. However, traditional delivery methods are often characterized by inefficiencies, such as high costs, long delivery times, and poor delivery accuracy. The rise of e-commerce and the growth of online retail have added further pressure to last mile delivery in these countries. To address these challenges, Physical Internet (PI) has emerged as a promising solution. PI is a new paradigm for logistics and supply chain management that aims to increase the efficiency, sustainability, and resilience of the supply chain. This study aims to assess the impact of PI on last mile delivery in developing countries, using a digital model-based approach. By analyzing the potential benefits and limitations of PI, this study will contribute to the literature and provide insights and recommendations into the implementation of PI-based scenarios in last mile delivery in developing countries.

Keywords: Physical Internet · Last Mile Delivery · Developing Countries · Digital Model

1 Introduction

Last mile delivery refers to the final leg of the delivery process, from the transportation hub to the customer's doorstep. In developing countries, last mile delivery is critical for ensuring access to goods and services for the population, particularly for remote and rural areas. The success of last mile delivery can greatly impact the economy, social welfare, and overall quality of life for the people in these regions [5]. It is also crucial for the growth and expansion of e-commerce, as last mile delivery directly affects customer satisfaction and loyalty. Additionally, last mile delivery in developing countries faces unique challenges, such as infrastructure constraints, security issues, and limited access to technology and resources, making it even more important to address and improve [2, 6].

In big cities of developing countries, logistics faces several challenges that can negatively impact the delivery process [8,11]. The measurement of logistics performance in developing countries is hindered by the absence of data, but estimates made by the World Bank (WB) show that these countries consistently fall below the average of the global logistics performance index [10]. On average, the logistics performance index for a developing country is about half that of a developed country. Reda et al. [19], conducted a study on the logistics and supply chain features of developed, emerging, and developing countries. After conducting an extensive literature analysis of over 300 articles, they found that the main logistics issues for developing countries are related to city logistics. They noted that these countries face significant challenges such as high traffic congestion, unsafe roads, rapid population growth, inadequate infrastructure, and expensive, unreliable vehicles. They also mentioned that developing countries are currently exploring various topics related to city logistics such as crowd-shipping, urban consolidation centers, e-commerce delivery, and alternative transportation modes. Despite efforts to improve city logistics in developing countries, the problem remains persistent and has a significant impact on their economy. Developing countries face numerous structural problems [18], including low income, dependence on specific sectors, low productivity, limited employment opportunities, poor health and education, and corruption, as well as specific city logistics issues such as poor road infrastructure, old vehicles, and lack of parking spaces. This is particularly true for Southeast Asian countries like Cambodia [17], whose economy is centered around large cities experiencing rapid population growth. As a result, the main research question for this project is how to improve the performance of freight transport activities in the cities of developing countries through the use of existing means and infrastructure.

These challenges can lead to increased costs, decreased customer satisfaction, and reduced efficiency for businesses. Addressing them is critical for improving last mile delivery in developing countries. We made the assumption that Physical Internet (PI) has the potential to solve these challenges by leveraging its key principles and feature. [3]. The PI aims to optimize the flow of goods, people, and information across the supply chain, with the goal of reducing delivery times and increasing the efficiency of last mile delivery. Additionally, PI provides a platform for sharing resources, such as delivery vehicles, delivery hubs, and sorting centers, reducing the need for businesses to invest in their own infrastructure. The use of PI can also lead to increased security during last mile delivery, with enhanced security measures such as real-time tracking and predictive delivery models reducing theft and security issues. Furthermore, PI leverages digital technologies and geolocation systems to provide more accurate and efficient addressing systems, reducing the difficulties in locating customers in big cities. Lastly, PI is designed to minimize waste and optimize the use of resources, leading to increased sustainability and reduced environmental impact in last mile delivery.

By addressing these challenges, PI has the potential to change last mile delivery, leading to improved efficiency, cost savings, and customer satisfaction. This leads us to formulate the following research Question: “What are the potential benefits of Physical Internet in last mile delivery in developing countries?”. In

this paper, we aim to assess this potential using experiments based on a digital model. Section 2 proposes an overview of the PI paradigm and its potentiality to improve last mile delivery. Section 3 highlights the Research Methodology applied to obtain the results. Section 4 analyses the results and discusses them.

2 Literature Review

2.1 Overview of the Physical Internet

The PI is a concept aimed at revolutionizing the way physical goods are managed, transported, stored, and used for a more efficient and sustainable global logistics system [16]. The PI draws from the principles of the Digital Internet (DI), such as openness, encapsulation, and universal interconnection, to transport physical goods in standardized containers, similar to data packages in the digital world [12]. The PI is defined as “a global logistics system built from the interconnection of logistics networks through a standardized set of collaboration protocols, modular containers, and intelligent interfaces for increased efficiency and sustainability [3]. The PI aims to interconnect logistics networks, share assets, use intermodal transportation, and employ digital technologies for improved efficiency and sustainability. It is based on the principles of standardization, interoperability, collaboration, and modularity [3]. These principles work together to streamline the delivery process and enhance the overall efficiency of the supply chain.

Standardization in PI refers to the standardization of transportation processes, systems, and modes, ensuring greater compatibility and interoperability across the supply chain [16]. Interoperability, on the other hand, enables seamless and efficient flow of goods and information between all participants in the supply chain, allowing for greater connectivity and collaboration [14]. Collaboration, as a principle, fosters cooperation and information sharing among businesses, governments, and customers, contributing to a more efficient and effective supply chain. Lastly, modularity in PI leverages flexible and adaptable transportation modes, providing greater flexibility in the delivery process and increasing the overall efficiency of the supply chain.

By incorporating these principles, PI offers numerous benefits for businesses and customers alike, including improved efficiency, better utilization of resources, increased security, better addressing systems, and improved sustainability. Ultimately, the implementation of PI has the potential to revolutionize the logistics and delivery process, leading to increased customer satisfaction, cost savings, and more efficient, sustainable delivery processes.

The theoretical benefits of PI have been extensively researched and demonstrated in various applications, primarily in developed countries [22]. According to Matusiewicz [13], the PI is an innovative logistics network built on technology and collaboration that deserves the attention of both academics and practitioners. However, there is a gap in understanding its potential impact in the rest of the world, particularly in developing countries [7]. This remains an area that requires further exploration.

2.2 State of the Art of the PI in Developing Countries

However, the implementation of the PI in developing countries faces challenges such as the need for coordination and collaboration between transportation providers, regulatory and legal barriers, and a lack of willingness to adopt the new mode of operation. The PI has the potential to revolutionize transportation and logistics, improving efficiency, sustainability, and resilience [19]. It could create a more connected and efficient global supply chain, benefiting consumers, businesses, and the environment [2].

One major challenge is the need for greater coordination and collaboration between different transportation providers and logistics companies. This requires the development of new standards and protocols for intermodal transportation and the sharing of data and infrastructure [15]. In addition, there are regulatory and legal barriers to the development of the PI, including differing safety and environmental regulations across different countries and regions. Basically, such a paradigm shift in logistics requires significant transformations at various levels [9], leading to the need for an adapted information system using advanced technologies to enable the hyperconnection of actors, allowing for increased and standardized information sharing and massive data storage. It is necessary for the actors to evolve towards this new mode of operation and to engage in the effort [7]. The ALICE (Alliance for Logistics Innovation through Collaboration in Europe) grouping has recently published a roadmap formulating the important steps and associated prerequisites for the implementation of the PI by 2050 in developed countries [1] (ALICE-ETP, 2020). Despite these challenges, the PI seems to have the potential to revolutionize transportation and logistics in developing countries, by improving efficiency, sustainability, and resilience. By optimizing the movement of goods and people across different modes of transport and leveraging digital technologies, the PI could create a more connected and efficient global supply chain, benefiting consumers, businesses, and the environment.

In conclusion, while the PI is slowly being implemented globally, it needs to be more widely known and adopted, especially in developing countries. This project aims to determine whether or not the PI is of interest in solving the issue of improving the performance of freight transport activities in cities of developing countries through the use of existing means and infrastructures. The implementation of the PI in developing countries may face challenges, but its potential to revolutionize transportation and logistics makes it worth considering as a solution.

3 Research Methodology

3.1 A Digital Model to Conduct the Experiment

The popularity of hybrid simulation (multi-method simulation modeling), which combines two or more modeling methods such as Discrete-Event Simulation (DES), System Dynamics (SD), and Agent Based Simulation (ABM), has rapidly

increased in the last two decades [4, 20, 21]. In this study, we will use a mix of DES and ABM to evaluate different scenarios of city logistics in developing countries with the goal of improving the PI paradigm.

To accurately model city logistics in developing countries, a multi-method simulation model architecture is proposed. (see Fig. 1) This model takes into consideration the unique characteristics of each stakeholder by modeling them as autonomous agents (see Fig. 2) using ABM and DES. The uncertain interactions between stakeholders are also captured using DES.

The environment of these agents is defined using a geographic information system (GIS), which considers factors such as geographical location and access to resources. The last-mile delivery of goods is modeled through interactions between various stakeholders in the network, simulating the order lifecycle process for each scenario.

The simulation results will be evaluated against key performance indicators (KPIs) such as economic, environmental, and technical performance for better decision-making. The proposed method will be tested in real-case scenarios in developing countries.

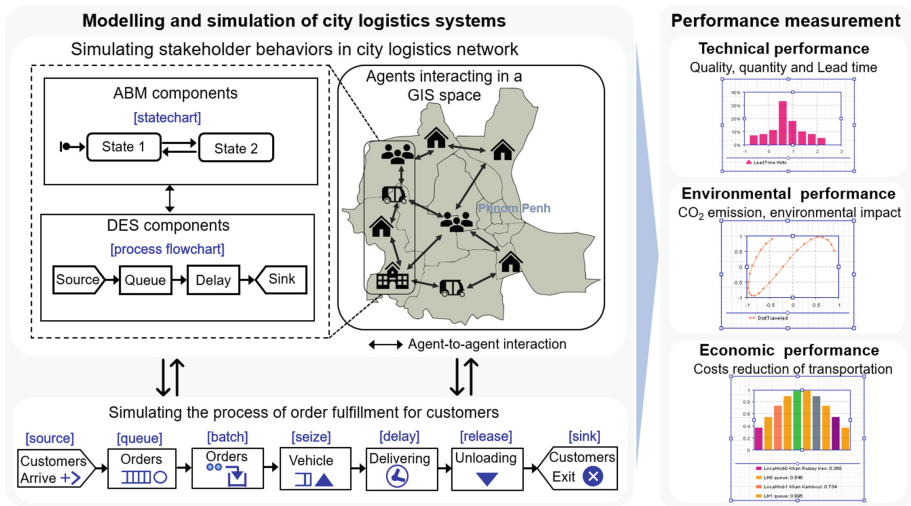


Fig. 1. Simulation modeling of city logistics using multiple methods in developing countries

Digital Model Assumptions. The company operates 24/7 and processes orders on a first-in, first-out basis during the center’s operating hours (7:00 am to 8:00 pm). The study assumes unlimited storage capacity and constant order preparation times, and only considers variability related to transport vehicle availability and vehicle speed related to traffic jam. The transport aspect of

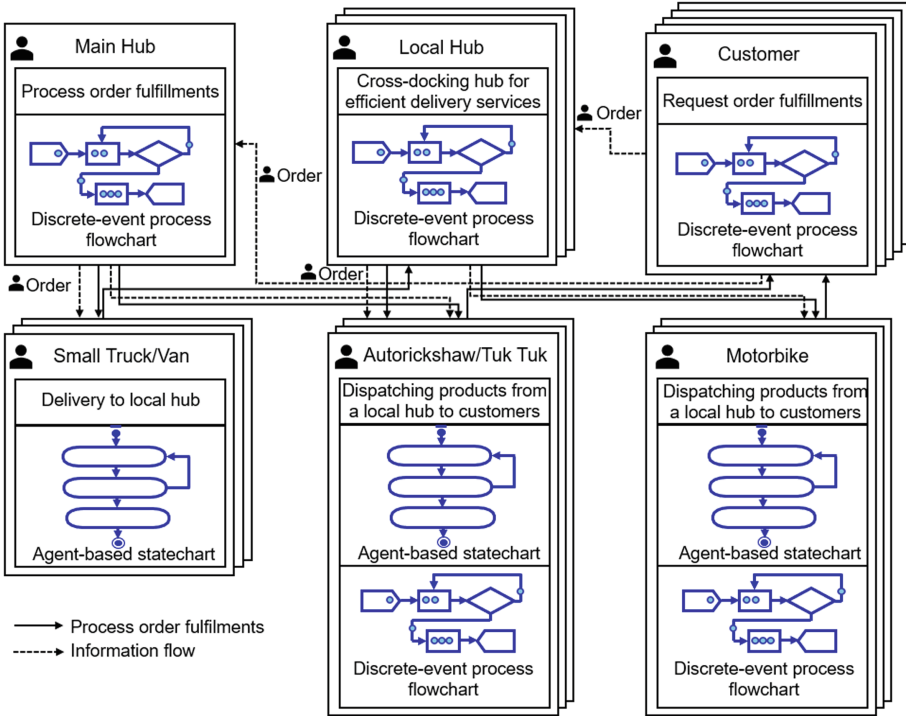


Fig. 2. Agent Description

the model involves the use of the company's own vehicles, primarily motorcycles, to ensure delivery throughout the day, depending on the capacity of the chosen vehicle type (motorcycle, van, tuk, etc.) and a prearranged schedule. The vehicle routing is based on the shortest path algorithm and takes into account the inherent speed characteristics of the vehicle, as well as the traffic conditions of the relevant area, including congestion issues.

Scenarios Tested. The purpose of this section is to establish a basic model as a reference for evaluating the potential usefulness of PI (PI) solutions developed in this research.

The scenario 0 is depicted in the accompanying Fig. 3. The scenario involves a business with one fulfillment center, known as Main, that serves as the storage and preparation center for customer orders in the designated region.

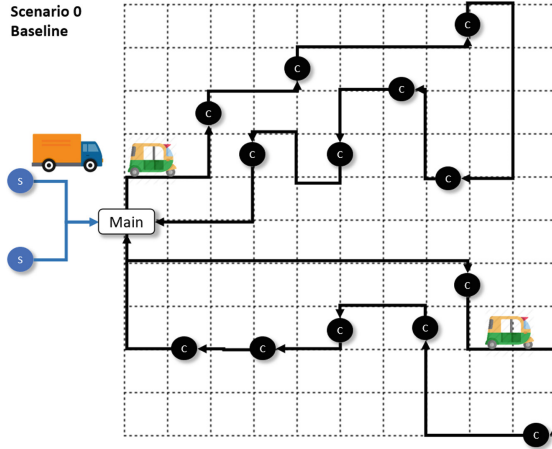


Fig. 3. S0 : the baseline

The scenario 1 (illustrated in Fig. 4a) proposes the addition π -hubs to support last-mile delivery in the city. The city is divided into zones affected to each π -hub. Each π -hub has its own fleet of vehicles to ensure delivery. The hubs are responsible for the preparation, shipment and delivery of orders in their territory, with restocking between the distribution center and hubs done through daily shuttles. The main stock remains at the distribution center with unlimited capacity. In this scenario, the PI hubs act as cross-docking platforms where incoming goods are unloaded, sorted and consolidated, and then loaded onto outgoing vehicles without storage, allowing for faster and more efficient delivery. The main process flows of order fulfillment take place at the π -hubs.

The idea behind scenario 2 (illustrated in Fig. 4b) is to bring the PI concept closer to reality by creating a shared, modular, standard, and interoperable transportation network that connects different transport networks, similar to how the digital internet operates. The use of modular components and standardized materials is crucial for the success of a network as it enables easy connectivity and seamless interaction with other networks.

In this scenario, the priority is on accessibility and a collaborative solution. To achieve this, the proposal is to make use of the numerous means of transport already available in developing cities, such as TukTuks and motorcycle cabs, instead of having each hub having its own fleet of vehicles. The transportation of goods is entrusted to third-party resources that are available on-demand, based on customer expectations and transportation opportunities around the π -hub.

The process in this scenario involves the π -hub receiving incoming goods from the main warehouse and sorting them according to their destination. The π -hub can then use on-demand vehicles from a transportation provider to pick up the sorted goods and deliver them to the customer's location, with the help of the PI Network and information sharing.

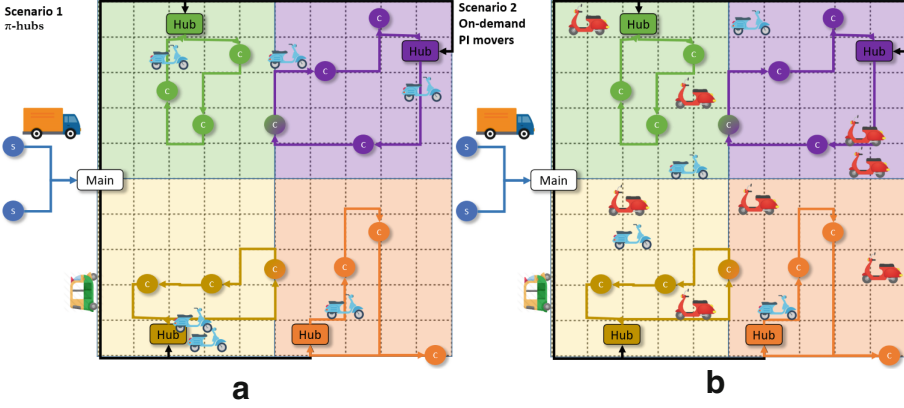


Fig. 4. (a) S1 : A Supply Chain with π -hub, (b) S2: with π -hub and on demand fleet

Key Performance Indicator Used to Assess the Simulation. The results of the simulation are analyzed using Key Performance Indicators (KPIs) to assess the effectiveness of the PI paradigm and the different scenarios. Lead Time is used to measure the transportation time, excluding the preparation time. The Lead Time KPI is used to evaluate the time dimension of the PI paradigm and the delivery of goods in the last-mile (See Eq. 1). LeadTime provides a clear measurement of the time taken from the preparation of goods at the main warehouse to their final delivery at the customer’s location, and helps to assess the effectiveness of the delivery process.

$$LeadTime = TimeOrderDelivered - TimeOrderPlaced \quad (1)$$

The cost function KPI is used to assess the financial aspects of the PI paradigm. It provides a measure of the costs incurred in delivering goods from the main warehouse to the customer’s location. It takes into account the type of vehicles used, the distance traveled, the fuel consumption, the spare parts replacements and the oil to calculate the overall cost of delivery. This KPI is important for evaluating the efficiency of the PI paradigm in a developing country context. To evaluate the financial aspect, a cost function is used, with the cost function for Scenario 0 and 1 being the same with the price being calculated based on a combination of a fixed initial fee per day and a mileage fare (see Eq. 2). But slightly different for Scenario 2 due to the use of an on-demand vehicle service, we consider a fixed fare for order pickup cost of 5\$ per pickup. The different values used to build the cost function can be found in Table 1.

$$Cost = \sum_{nvehicles} CostPerDay * NbDay + \frac{TotalDistance * VOC}{1000} \quad (2)$$

Additionally, a carbon footprint function is calculated to assess sustainability, which takes into account the type of vehicle used and the mileage traveled by each

vehicle. The carbon footprint function KPI is used to assess the sustainability of the PI paradigm. It calculates the amount of carbon dioxide emissions produced during the delivery of goods from the main warehouse to the customer’s location (see Eq. 3). This KPI is important for evaluating the environmental impact of the PI paradigm and its alignment with sustainable development goals.

$$CarbonFootPrint = \sum_{nvehicles} f(TotalDistance, Consumption, Type) \quad (3)$$

Table 1. Data used for KPIs

	Motorbike	TukTuk
Purchase Cost (\$)	3000	6000
LifeTime (year)	5	5
Cost per day Depreciation (\$/day)	2	4
Vehicle Operating Cost (VOC) (\$/1000km) (Maintenance)	76,4	131,6
Consumption (L/100km)	1,84	5,2
On-Demand fare	5\$ per course	–

In conclusion, these three KPIs provide a comprehensive evaluation of the PI paradigm in terms of effectiveness, efficiency and sustainability, which are key aspects of the last mile delivery performance in a developing country context.

3.2 Case Study Selection

The Little Fashion Company. The model is based on by the case of “Little Fashion Company,” a Cambodian e-commerce company located in Phnom Penh with which the researchers had a partnership throughout the research process.

An Experiment on One Week Data. The simulation has been runned on a one week sample of orders between the 02-08-2021 and the 10-08-2021. This correspond to 9100 orders placed by 8290 differents customers. The type of vehicle and their specifities are detailed in Table 2.

Table 2. Parameters of vehicles in each scenario

	Scenario 0	Scenario 1	Scenario 2
Vehicle Main to Customer	Motorbike	–	–
Vehicle Main to Hub	–	TukTuk	TukTuk
Vehicle Hub to Customer	–	Motorbike	Motorbike
Nb of Motorbike	57	57	100
Capacity of Motorbike	18	18	18
Nb of TukTuk	–	15	15
Capacity of TukTuk	–	50	50

4 Results and Discussion

After Running the simulation for one week for the three scenarios we observe that we were able to deliver respectively 8742, 8854 and 8856 for scenario 0, 1 and 2. As a reminder, there were 9100 orders placed during this week. So the use of PI Scenarios let us reduce the non-served order rate from 4% to 3% so it is 100 extra orders which can be delivered.

Considering the Leadtime, Table 3 summarizes the results obtained. The Median LeadTime is 8.19, 5.11 and 3.72 h for scenario 0, 1 and 2. Adding LocalHub with motorbike fleet can improve the leadtime by 37% compared to the baseline. However, using LocalHub and on-demand fleet improve the median leadtime by 54% and let us gain one additional hour on the delivery which is quite interesting for a Last Mile Delivery on e-commerce. Meanwhile, the maximum leadtime could seem quite high, however it can be explained by the orders overlapping between two days and which are not delivered the same day it is received. This maximum Leadtime is reduced from 25 h to 19 h. It is an improvement of 24% compared to the baseline.

The Carbon Footprint for each Scenario is detailed in the Table 4. The Scenario 0 considers only TukTuks, Scenario 1 and 2 consider a mix of TukTuks and Motorbikes. The results show that the use of TukTuks as a mode of transportation results in a higher fuel consumption compared to motorcycles, leading

Table 3. Descriptive Statistics(in hour) on LeadTime for Each Scenario.

	LeadTime in hour				
	STD Dev	Min	Median	Mean	Max
Scenario 0	4,84	0,19	8,19	8,36	25,47
Scenario 1	4,46	1,17	5,11	6,61	20,38
Comparison to Scenario 0	8%	-515%	38%	21%	20%
Scenario 2	4,37	1,18	3,72	5,61	18,99
Comparison to Scenario 0	10%	-520%	54%	33%	25%

to a higher carbon footprint in Scenario 0. However, by utilizing a hub system and utilizing lighter means of transportation such as motorcycles for last mile delivery, the company was able to achieve a significant reduction in their carbon footprint. In fact, there was a 60% decrease in carbon emissions from the baseline, going from 17.8 tonnes of CO₂ produced per week to only 7 tonnes of CO₂ produced. The implementation of an on-demand vehicle system leads in a decrease in the total distance covered by the vehicles, leading to a slight reduction in the company's carbon footprint from 7.10 tons of CO₂ to 6.90. However, this decrease should be considered with caution as the transportation still occurs and emissions are still produced, only the responsibility is transferred to the on-demand vehicles. Thus, it can be seen as a shift in responsibility rather than a genuine reduction of carbon emissions between Scenarios 1 and 2.

Table 4. Carbon Footprint for each scenario

	Carbon Foot Print			
	Main to Hub	Hub to Customer	Total (ton of CO ₂)	Comparison to Scenario 0
Scenario 0	17,8		17,8	–
Scenario 1	0,602	6,5	7,10	60,7%
Scenario 2	0,602	6,3	6,90	61,2%

The Table 5 summarizes the cost of each scenario. The cost calculation takes into consideration factors such as depreciation, maintenance, and fuel expenses for the vehicles. For the on-demand fleet scenario, the cost is calculated based on a fixed initial fee and a mileage fee. The scenario with its own fleet of TukTuk (Scenario 0) incurs the highest weekly cost of 10,000\$. By switching to a fleet of motorcycles in Scenario 1, the cost is reduced by 30% to 6,986\$. The implementation of an on-demand fleet (Scenario 2) results in an even greater reduction of 73% to 2,705\$, with a fixed pickup cost of 5\$ (which is an estimated value).

Table 5. Vehicle Operating Cost for each Scenario

	Vehicle Operating Cost (USD)			
	Main to Hub	Hub to Customer	Total (USD)	Comparison to Scenario 0
Scenario 0	10000		10000	–
Scenario 1	382	6604	6986	30%
Scenario 2	382	2460	2705	48%

5 Conclusion

The digital model based study of PI implementation for last mile delivery in a developing country reveals that it can lead to significant improved delivery performance, reduced carbon footprint, and decreased costs for the company. The results of the simulation for a one-week period show that the implementation of PI leads to a 1% orders increase in the number of orders delivered, a reduction in the median lead time by 54%, and a decrease in the carbon footprint by 60%. Additionally, the cost reduction from 10,000 to 2,705 demonstrates the potential financial benefits of implementing PI in such a context. These results suggest that PI can play a crucial role in improving last mile delivery in developing countries and can lead to a more sustainable, efficient and effective supply chain system.

In conclusion, the results of this digital model based study highlight the potential of PI in enhancing last mile delivery in developing countries. However, it is important to acknowledge the limitations of this study such as the one-week sample, limited stock information in the digital model, and lack of collaboration and shared transportation in the model. Moreover, it would have been interesting to compare our results to existing studies in the literature, however we have not found any relevant article to be compared with. The study is currently focused on a single company, therefore, it would be interesting to include other companies to examine the potential of coordination and collaboration between them. Another interesting aspect to consider is the scenario of the growth of electric vehicles in developing countries and how this can be analyzed through the digital model. Additionally, the model could be used as a decision support tool to determine the optimal placement of π -hubs. Further research is needed to expand the simulation and address these limitations to provide a more accurate evaluation of the impact of PI on last mile delivery.

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