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CONCEPTING FREIGHT HOLDING PROBLEMS FOR PLATOONS IN PHYSICAL INTERNET SYSTEMS

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Abstract: For the sustainability of future logistics systems, Physical Internet is one of the most determined idea. Initial solutions and ideas exist, but the development in this area is far from complete. In our opinion, vehicle technology trends such as interconnected, autonomous vehicles and the platooning system are an important opportunity for the development of logistics network. This research aims to investigate how these new types of processes can be modelled using the results of a freight holding problem. The article surveys the possibility of reconfiguration of the platoons in the Physical Internet system by creating a virtual transfer point.

1 Introduction

Given the increasing attention for the worldwide sustainability receiving from academics and specialists it is important to create a more efficient and effective supply chain model. One of the most widespread concepts of the future logistics network is the Physics Internet system.

Physical Internet (PI) is a new concept designed to implement the digital world into the processes of the physical world. One of the most important elements of this is the so-called PI containers, which are also based on the digital world. As in the Internet network, not data, but data packets flow, in the PI network goods as a standard packet will be store or transport. The expected efficiency can be achieved with a properly established network of elements in the network. The Physical Internet-based logistics network has recently been the subject of increased interest in both environmental, economic and social benefits, so it can be said that the developments and research have not yet been completed [1,2].

According to our opinion, the results of the vehicle technology development open up important opportunities for logistics systems [3]. Transport is one of the most dominant factors in the sustainability of the logistics network, and we can define the primary goal of reducing it's wastes. Transport, which means bridging geographical differences, is most often carried out by road. It can occur in any form from heavy-duty vehicles (HDVs) to small electric vehicles typically from cities. Among the trends in vehicle technology in our article, we concluded that the examination of the platoon systems could bring further improvements in logistics systems [3]. It is indispensable to ensure the communication of the vehicles in order to establish the platoon vehicle tracking system, so they become connected. This system was mostly examined from the side of the vehicle related results, and their logistical utility have not been shown so far.

This research focuses on the potential from development of platoon systems and connected vehicles. Using the results of the existing freight holding problem, we analyse how we can model these new types of processes in a Physical Internet-based network. After presenting the concept of Physical Internet in this article, we will survey the results of the freight holding problem research area. Finally, we present the structure of a future model which provides a dynamic, real-time reconfiguration for the platoons. This implies the creation of virtual transfer points, which is providing a meeting point for convoys to exchange their vehicle members. The transfer point can be placed anywhere in the network where two or more vehicles are carrying out the reconfiguration can safely stop (stops, parking lots, resting places, waiting stations, etc.). The purpose of the model is to optimize the location of the virtual point.

2 Physical Internet and vehicle platoons

The current operation of a global logistics system is unsustainable from a social, economic and environmental point of view [1]. There are basically no limits for customers to buy any product in any quantity from anywhere. Companies are constantly facing to this demand of performance, which they are less able to meet with their current system. To prove this, thirteen general symptoms have been presented in the article written by Montreuil [1]. The researchers created the theoretical concept of Physical

Internet in order to achieve effective and sustainable global operation. The point of the idea is to revolutionize logistics networks, including the storage, handling, and transportation of physical objects across the globe [2].

The concept of the Physical Internet has used the foundations of the digital world and developed the operational features of the future network by its analogy. The foundations of the new paradigm were laid down by Montreuil (Figure 1) [4].

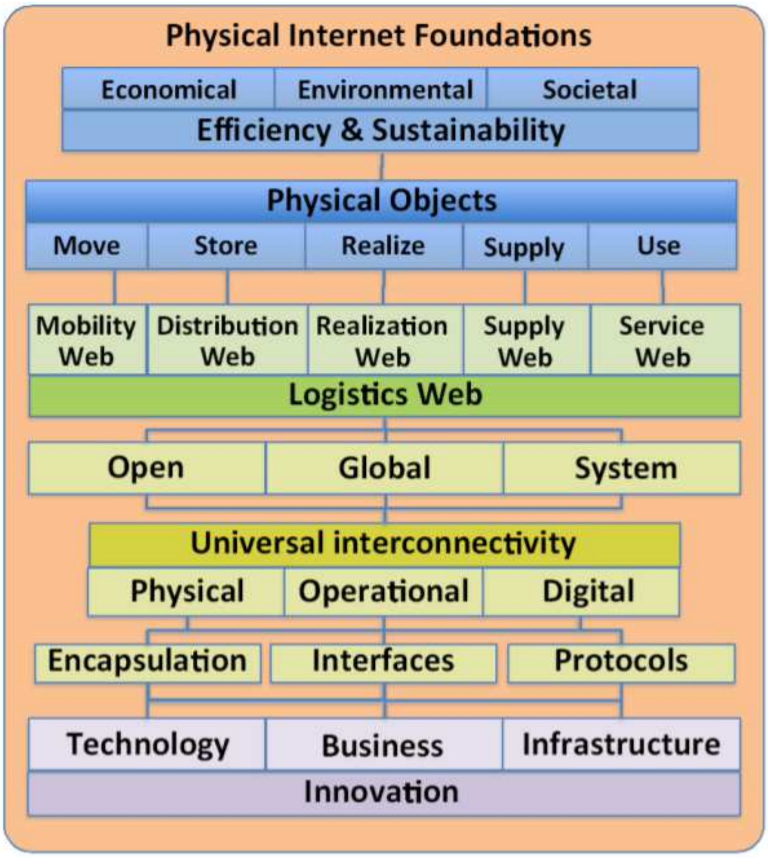

Figure 1 Physical Internet Foundations [4]

This is one of the most important concepts for the future network, but the breakthrough is still waiting. The primary goal of the Physical Internet is to define economic, environmental and social efficiency and sustainability. It uses a completely new approach to achieve this, because the physical objects would be handled in a standard container for specific purposes [1]. One of the strongest ideas follow the model of the ISO containers, and the sizes can be constructed according to that. [5] In the network, these packets carry the necessary information, and without knowing what is exactly in it, the next user or manager capable of doing all the required tasks, such as storage, loading or transportation.

The second cornerstone of the PI network is world-wide interconnectivity, at a physical, operational and digital level. Interconnectivity as a logistic quality feature ensures seamless information exchange and communication between entities in the network [4]. This concept is parallel to the trend in vehicle technology such as connected vehicle and the vehicle platoon system. The vehicle platooning concept, like the Physical Internet, was created to eliminate the prevailing negative effects, such as excessive energy consumption, congestion or pollution. In order for the vehicles to be able to ad-hoc create platoons, communication between them is essential. Currently, this is limited to a manufacturer's vehicle in practice, this method not feasible in more widely area, since currently there is no standard language [6]. For this reason, we can say that for this research, the most important feature for us is the universal interconnectivity of the Physical Internet, which would ensure that everyone 'speaks the same language' in our system.

The collectively called Cooperative Adaptive Cruise Control (CACC) system allows to the vehicles for following each other very closely. Thanks to this technology, it is possible to build a system where the leading vehicle is automatically followed by other vehicles. In this case, only the first vehicle should be manually driven so the other vehicles are connected to the driver using wireless communication technology and are controlled by it. With the platoon system, the vehicles are moving much closer to each other compared to manual driving, bringing both economic and social benefits [7].

To ensure the platoon system, vehicle routes must be synchronized. Vehicle synchronization means connecting two or more vehicle routes. According to the same authors, the spatial dimension of synchronization determines the place where the vehicle can be synchronized (at fixed points or at variable points), and the temporal dimension determines the sequence where the vehicles meet (at the same time or with precedence). Types of synchronization are summarized in the first table by distinguishing between temporal and spatial synchronizations [8].

Table 1 Type of synchronization [8]

		Temporal synchronization	
		Simultaneous	With precedence
Synchronization	Fixed transfer point	**Fixed point, Simultaneously**	**Fixed point, Priority**
	Variable transfer point (design result)	**Variable point, Simultaneously**	**Variable point, Priority**

During using their logistical application, vehicles from the same or different directions, but are in one direction can be organized in one platoon. The next figure (Figure 2) shows an example of a platoon formed by two vehicles, the number 2 vehicle makes a detour to create a connection [7].

According to our opinion, the greatest benefit of this can be achieved by using Physical Internet-based network, since in this case the open, global logistics system are available. We consider the system based thinking important, because in order to create a platoon, some vehicles can make a detour to extend their own route. In this case, the vehicles make a compromise and differ from their planned route in favour of reach the promised savings by the platoon [9].

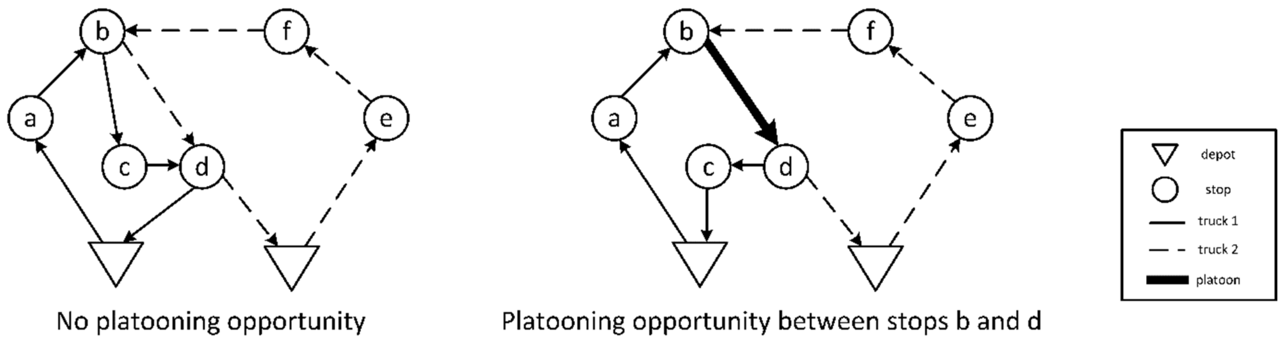

Figure 2 Route modification in order to create a platoon [7]

3 Freight holding problem

The operation of transfer-based networks can have significant advantages over direct point-to-point networks, such as reducing operating costs. The reduction is caused by the fewer roads made by the vehicles, as not all vehicles have to make the full journey between their starting station and their destination, because of use specified transfer points may establish joint routes. The freight holding problem is related to reloading at such transfer points. When a vehicle arrives at a transfer point, it is necessary to decide how long to wait for it to be worth it so waiting for a decision can lead to extra costs or save costs. Most of the publications on the issue are related to public transport, but there are some studies are dealing with holding decision problem for freight and logistics systems. Vehicle tracking is not a novelty in the logistics, and the exact location of the vehicles available with this. It can be said that, unlike passenger transport, in logistics systems, goods and vehicles are in an environment with a lot of data. In the following, we review the achievements of the transfer and freight holding problem. In our article, we base on four articles from the related research, two is based on public transport systems and two related to freight transport [10].

Randolph Hall et al. [11] examined the optimum waiting time at the transfer station. The target function minimizes the waiting time obviously this should be between two consecutive bus arrival times. The aim is to find the departure time when the total waiting time for all passengers is minimal. By increasing the expected arrival time of the next bus, they got four different target function values. From the results it can be concluded that as soon as the delay has increased significantly, it is better to start the bus immediately, otherwise while the value of the target function was lower than zero waiting time, it is better to hold the bus [11].

Xu Jun Eberlein et al. [12] uses real-time data. In their articles, they examined what stations and for how long it is worth to hold for the bus to minimize the waiting time for all passengers. It is important to note that in this case, minimizing the waiting time of the passengers involves minimizing the change of travel. Therefore, it is believed that the problem examined here is the most common for high-frequency transfer lines. Taking into account the assumptions of their method, the analysis has found that real-time information on vehicle routes may be sufficient to determine the holding decision and the real-time passenger demand information may not be necessary. Additionally, holding the vehicle does not have a significant impact on subsequently followed vehicles, which means that the length of the rolling horizon can be very small, which allows for real-time application of the algorithm [12].

Chen and Schonfeld [13] consider a number of logistical problems that could interfere with the operation of the system. In this work, the fast scheduling decisions are optimized in the changing environment. A vehicle control method has been developed that can help operators determine during an optimization process whether already vehicles should be dispatched immediately, or held for other certain vehicles. The decision-making methodology helps when the coordinated freight operations are disrupted. The target function is the sum of the costs of holding and non-holding. For each finished vehicle on the transfer point, a binary variable indicates the holding decision. To simplify the problem, authors start from a single hub operation that shows a symmetric demand between any incoming and outgoing routes [13].

Yanshuo Sun and Paul Schonfeld [14] examined the effect of correlation between vehicle arrival times. Most of the solutions found in the literature make vehicles arrive independent of mathematical simplification. This, however, sacrifices realism, since there are correlations in the real world. For example, as a result of bad weather or congestion, a bunch of vehicles may arrive. The impact of positive correlations, the vehicles arrive in groups. The proposed model is similar to the previous article, because they also use to help the driver optimization decision, taking into account the various types of costs. Making obligation is necessary when a vehicle is ready and when a new vehicle arrival forecast is available. Figure 3 shows a simplified case where two incoming trucks arrive at the specified transfer terminal and depending on the arrival time of the vehicle, need to determine the start or hold of the outbound train [14].

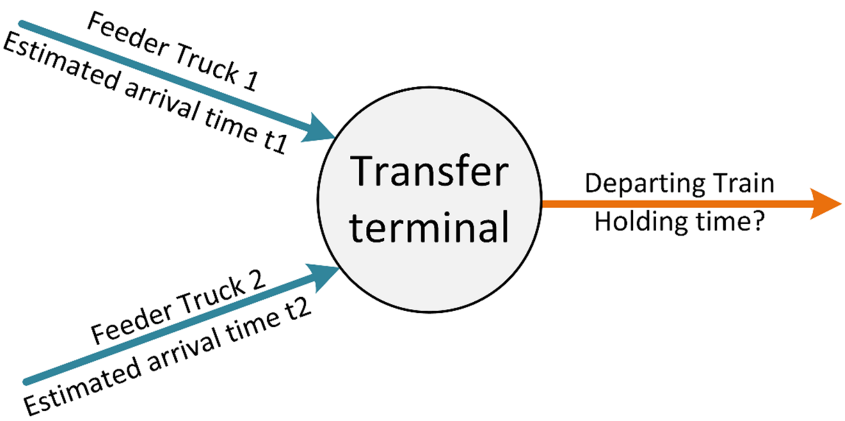

Figure 3 An example of two delayed arrivals [14]

Although there is only one decision variable, solving this optimization problem is difficult due to the goal is not convex. This means that any search algorithm may end on a local optimum. Based on their calculation results, it was determined that the correlation between the arrival time of the vehicles did not influence the expected value of the total cost. This has made the problem simpler, so it is enough to make the holding decision independently for every ready vehicle [14].

We can see that there are many solutions to the holding decision-making. Their common feature is that the target function is determined by time, such as waiting time or holding time. Public transport results clearly show that savings can be achieved by holding. The next two publications on freight transport examined the impact of the characteristics of the real system, as a result, some data is worth to be considered, but some factors are worth to be ignored. For example, designing with real-time based data can provide additional savings (reduction in waiting time). On the other hand, it is not worth considering the correlation of vehicle arrival times, as it has no effect on the expected value of the total cost.

4 Structure of the proposed model for platoons

Vehicle tracking systems have a big impact on logistical networks. In order to get maximum potential benefits of the platoon opportunity, it is required modernize the transport networks. If the required infrastructure is available, the constraints of the operating environment can be disregarded while examining the decision models, such as road width or road quality.

In the defined network, the functionality of the Physical Internet system can then be assumed. Thus, the fixed and predefined transfer centres are open for PI users, and vehicles and platoons are able to communicate and make decisions between each other. In our article, we investigate a general network based on the Physical Internet system where we can complete the network of existing terminals with virtual transfer nodes. In further analysis, we will define these virtual transfer point locations.

In the network, vehicles move in a platoon from the starting position to the destination. The creation of platoon is motivated by the common goal, because if they are connected and follow each other, they can enjoy the benefits of the platoon, even making compromises of detours [10]. As discussed in the second chapter, there are vehicles in the system, which are connected to the platoon by leaving their - presumably the shortest- original route and they join the platoon with a small detour [10]. We consider it worthwhile examining the benefits of the system if we define further virtual nodes in addition to the fixed transfer locations. These virtual transfer points provide the reconfiguration of platoons which allow a vehicle to connect to platoon which has more favourable route for the vehicle compared to its original platoon.

The problem to be examined is that if there is an additional possible node (crossroads, stops, parking) for the existing terminal system of a general PI network, where it should be located depending on the current shipments, so what should be the *x* and *y* coordinates of the location of the virtual reconfiguration point. The information needed for configuration is carried by each vehicle as its starting point, destination, departure time, and arrival time to the destination.

When determining the virtual transfer point, information about the vehicles need to be examined. It will then necessary to define the reconfigurations that have a great advantage for the network. The logistics network is defined by vehicles, roads, fixed stations, open terminals and virtual transfer points, starting locations and destinations. Thus, there are predefined open terminals in the logistics network. They are fixed and are capable of receiving and transhipping more vehicles. Each predetermined centre is characterized by a service time corresponding to the transhipment time. Accordingly, a platoon incorporating the current number of vehicles dispatch the specified intervals. In addition to this, there is a virtual transfer point in the current study where vehicles can change platoon, so they can reconfigure themselves. In the PI logistic network, relocation requires that the vehicle that wants to change the platoon need to arrive sooner or at the same time as the platoon to which it want to connect. Otherwise, the vehicle cannot exchange the platoon. This means that in the presented model we assume IV. type of synchronization based on categorization by Makonwska et al. [8].

The proposed structure for the virtual transfer point is explained via an example (see Figure 3).

In the example, objects labelled with 1,2,3 are the starting points, and the objects labelled 1', 2', and 3' are the destinations. The first figure (Figure 4-1) shows the initial state, where from each starting points the vehicles with common destination dispatch to form a platoon and arrive at the one or more destination. In this case, there is the advantage and disadvantage of platoon systems, as there are vehicles that make a detour for the benefit of the platoon. As we can see on the figure, these are the 4,5,10 and 11 vehicles. In the network, each base station is accessible to each destination, and each destination is directly accessible in both directions. Analysing the Physics Internet system, we interpret a global and open network. The second figure (Figure 4-2) on the right shows the purpose of the presented model, thus creating a virtual transfer point. By defining a virtual transfer point, the platoons can save additional unnecessary routes, thus achieving a more sustainable operation in the system. At this transfer point, the reconfiguration is made, taking into account the previously mentioned synchronization conditions.

The problem defined by the example is the optimization of the virtual transfer point location. The structure of the proposed model is shown in Figure 5.

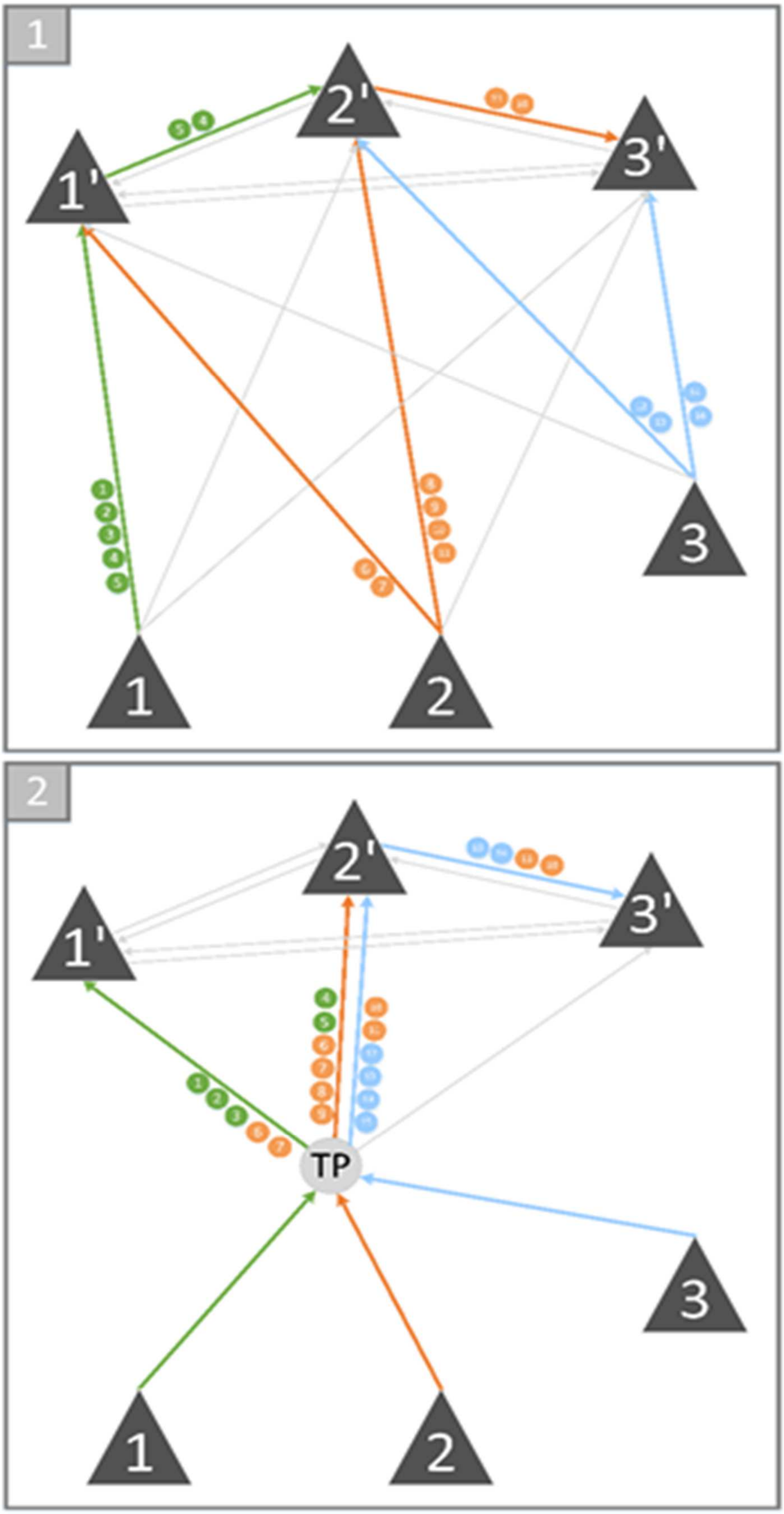

Figure 4 Example of the virtual transfer point optimization in Physical Internet network

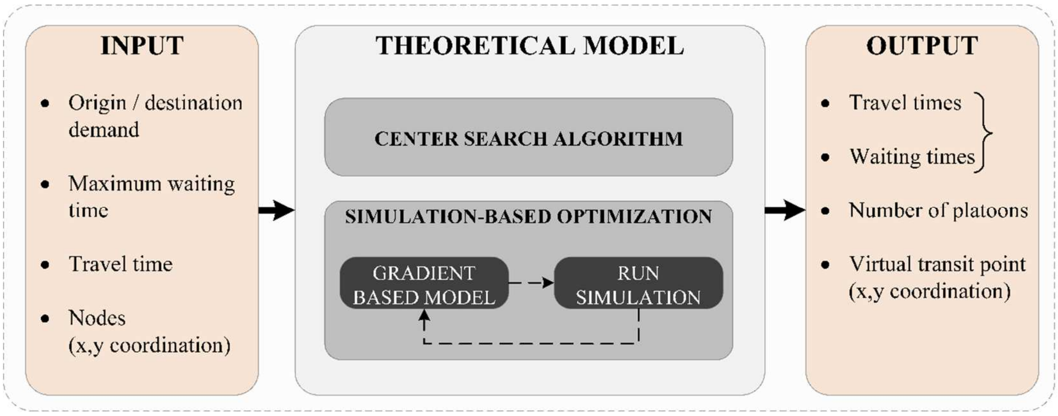

Figure 5 Theoretical model for virtual transfer point optimization in Physical Internet network

The following information is the input of the model:

- the predefined origin-destination demand,
- maximum waiting time,
- travel times between stations and
- the location of the origin and destination (*x* and *y* coordination).

Assuming the fourth type of synchronization, as the model input requires interpreting a maximum waiting time that the sooner coming platoon have to wait in order to the reconfigure to the later arriving platoon.

The task of the model is to optimize the location of the virtual transfer point, for which we have two options:

- One is a centre search analytical algorithm and;
- the other is a simulation-based optimization.

Analytically we use the result of centre search using coordinates algorithm. Figure 6 illustrates the process of reviewing the simulation optimization process. Accordingly, we determine the beginning of the simulation, transport in routes, terminal locations and demand values. At each origin stations, the system will generate platoons from the ready vehicles at specified times. Then the simulation assigns an initial virtual transfer point. The vehicle platoons go through the assigned transfer point before the destination. When a platoon arrives at the virtual transfer location, the model executes the real-time reconfiguration taking into account the defined maximum waiting time. Based on these, the following decisions can be made for the vehicles belonging to the platoon:

- Stay connected to their own platoon;
- Configuration themselves for a more favourable platoon;
- Waiting for a favourable platoon arriving within a maximum waiting time.

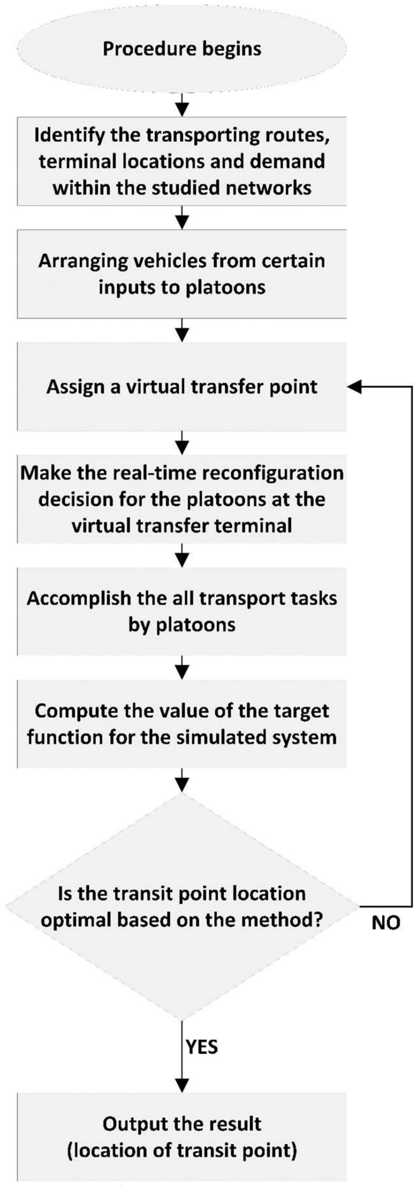

Figure 6 Virtual transfer point optimization in Physical Internet network

After making the decisions, the simulation performs the required transport tasks and then calculates the value of the specified target function after all the transport tasks have been completed. The next step in the process is to examine the optimal location of the virtual transit point based on the gradient method. The perfect method goes to the optimal location by using the largest reduction direction. So, run the simulation multiple times from a particular location to the coordinate in all directions, the simulation selects the *x*, *y* coordinate pair that has the lowest target function value. If the method does not find a better location placement for the simulation, the process is over and get the result of the *x* and *y* coordinates of the virtual transfer point. In case of the location is not optimal because of the simulation will find a more favourable position in the direction of the coordinate, the simulation will run again after assign the new location of the virtual transfer point.

In optimization, the goal is to minimize the time spent in the system by all vehicles. The distance travelled is directly proportional to time and the virtual transfer points do not have creation and deleting costs, so, in our opinion, the time is the most important feature of the system.

The time spent in the system for a vehicle is interpreted as follows, the arrival time of the vehicle at the departure station to the destination via the transit point, including the all travel and waiting times. Comparing the two methods with a lower target value of the transit point – so the lower sum of time spent in the system by all vehicle is accepted.

5 Conclusion and future works

Physical Internet is one of the most determined ideas for the future logistics system. Its fundamental goal is social, economic and environmental sustainability, which is realized through the open global logistics system. The cornerstone of an open system is to ensure the flow of wireless communications and information. If we assume these features, we can achieve a number of other benefits by implementing vehicle technology trends. Such as connected vehicles or platooning systems associated with interconnection. In this article we examined how we can model new types of processes using existing freight holding solutions.

In the process that we define, the vehicles used platoon system in a Physical Internet-based environment. To make better use of the benefits of the platoon system, we defined a virtual transfer point in the network where the platoons can reconfigure themselves. By using the reconfiguration, the vehicles can continue their routes in a platoon what is more advantageous to them, with synchronization conditions, a system-level based improvement can be achieved. This can be achieved with a system-level improvement. The purpose of the model is to find the optimal location for the virtual transfer point for reconfiguration.

The results of defining the virtual transhipment for the platooning reconfiguration as defined in the Physical Internet system belong to the basic phase of our research work. The next step in future research is to create a simulation model for the validation of the presented design, and then to examine the results of the simulation through its analysis.

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