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Comparison of Centralization and Decentralization of Physical Internet Through Gamification

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Abstract: *Centralization and decentralization are the two common organizations in freight transport. The first relies on a central authority who optimizes and establishes transport plans for all carriers for global- interest, while the second, presented by the physical internet in this paper, lets carriers optimize their own transport plans for their self-interest. The outcome - efficiency and effectiveness - could be different. This paper aims to use the concept of Price of Anarchy (PoA) to compare the outcome of the two organizations. Due to the complexity of actual freight transport market, this paper adapts the gamification methodology to investigate the two organizations. A freight transport game was developed for simulation. The outcome of the two simulated are then compared. The results show that the centralization outperforms in terms of global efficiency and effectiveness; while decentralization is better individual incentive. However, the PoA varies depending on information revealed.*

Keywords: *Physical Internet, Freight Transport, Centralization or Decentralization organization, Price of Anarchy, Gamification*

1 Introduction

Freight transport has been dramatically growing due to increasing global trade and economic development. Nowadays, Freight transport systems (FTS) are more and more challenged by new markets and new technologies. This entails the need for innovative solutions to develop a more sustainable and efficient FTS.

From this perspective, recent logistics paradigms aim at decentralizing logistics organization for agility and sustainability. Montreuil (2011) and Ballot et al. (2014) proposed the Physical Internet (PI) as a shared, interoperable, and decentralized transport network, which aims at seamlessly interconnecting currently independent transport networks and markets to increase profitability and efficiency.

Different from integrated or centralized organization that involves a control by a central planner who optimizes and establishes transport plans for all collaborating carriers. Decentralized organizations, like (PI) allow carriers to optimize their own transport plans for their self-interest to maximize their individual profit; meanwhile a rule-based organizer will manage collaborative activities with respect to global interest. They offer greater independence and flexibility for carriers. However, they could be harmful to global optimum obtained by the centralized organizations.

Despite aforementioned theoretical advantages, the performance - efficiency and effectiveness - of decentralization still needs to be further investigated compared to centralization, especially in the framework of the Physical Internet with possible transshipment between carriers at hubs. The concept of "Price of Anarchy" (PoA) is used for performance comparison. In this work we study two questions, how to measure the performance of decentralized organization compared with centralized one, and how the strategy convergence will affect the performance of decentralized organization.

We aim to obtain some constructive and practical guidance and implications for companies who consider centralizing or decentralizing the transport management.

2 Methodology

To investigate the centralized and decentralized organizations in real practice, we adopted the gamification methodology and developed an online freight transport game. The methodology of gamification is adopted because of the difficulty to apply the two organizations for a real life case study, and because of the complexity of actual freight transport market that is highly dynamic and open. Gamification is often considered as an effective approach to simulate highly complex real-life cases (Hamari et al., 2014).

The game is composed by two versions: V.1 represents the current transport market, where carriers are encouraged to combine multiple shipments for economy of scale, but without the possibility of exchanging them, and V.2 which represents a PI network containing transit hubs to exchange and interconnect independent shipments to increase profitability and efficiency; in this version the shipment's reallocation is allowed.

The game is based on a combinatorial auction process that aims to find the optimal allocation of resources that minimizes the overall cost of the transport market by taking into account the interest of each player.

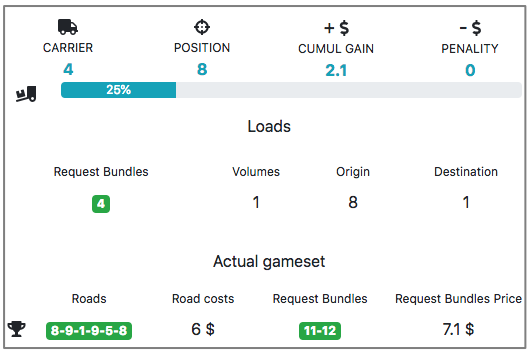

Figure 1: Online user interface of the Freight Transportation Game

Three scenarios have been played in both versions (current market and PI network) to compare the outcome of the centralized and decentralized organizations. It is important to note that, as input for all scenarios, transport requests and carrier maximal capacity are the same. The only difference of input is the price proposed by each carrier, and, therefore, transport plans and output are also different, as well as the total cost.

Scenario 1: represents the centralized model wherein a central authority optimizes globally the transport (e.g. minimizing the total transport cost), and proposes transport plans to all carriers. The later will execute exactly the plans proposed. For optimization, the authority should have complete information of the market and the carriers. In this scenario, the prices of requests are calculated and proposed by the centralized authority according to the market. As it is, this scenario can be considered as the optimal solution, and the upper bound of the level of performance.

Scenario 2: represents the decentralized model with no shared information. Each carrier will optimize his transport plans. Carriers set up a bidding price for each feasible request depending on their private strategies, then submit it to the organizer of the market. Their decisions are therefore selfish without considering global interest. The organizer will take into account all summited prices to allocate requests to carriers by minimizing the total transport cost. In this scenario, we assume that no information is shared between carriers.

Scenario 3: represents the decentralized model with limited sharing of information. In particular, we are interested in the question of how the strategy convergence will affect the performance of decentralized organization. For that, we decide to disclose the average margin of all carriers of Scenario 2 before running Scenario 3. In other words, this scenario has the same characteristics than the Scenario 2, the only difference is that, in Scenario 3 the organizer will communicate to carriers the average margin of the transport market, and let carriers take this information into consideration when proposing prices for request bundles.

The concept of PoA has been used to measure the performance degradation of the freight transport market due to the selfish decisions made by independent carriers in the decentralized organization. It has also been used to compare the performance of centralized organization (that yields the optimal social welfare) and decentralized organization (that could lead to the worst Nash equilibrium). In this study, we define the PoA as the ratio of optimal decentralized cost to the optimal centralized cost.

3 Experiment results

In this study, we discuss two types of KPIs: effectiveness and efficiency. The preliminary results show that the centralized model always outperforms in terms of global efficiency and effectiveness and it yields the optimal social welfare; while decentralization has better individual incentive for carriers. Regarding PoA, Scenario 3 of decentralization with margin information disclosing cost is higher in efficiency than scenario 2 of decentralization with no shared information.

Serval contributions have been made to the literature. First, we apply the gamification methodology and the concept of PoA to assess the performance of the two organizations. The innovative methodology may help researchers and practitioners better understand the challenges and stakes in the two organizations. Second, the developed game provides an efficient way to gather data for the future research work.

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